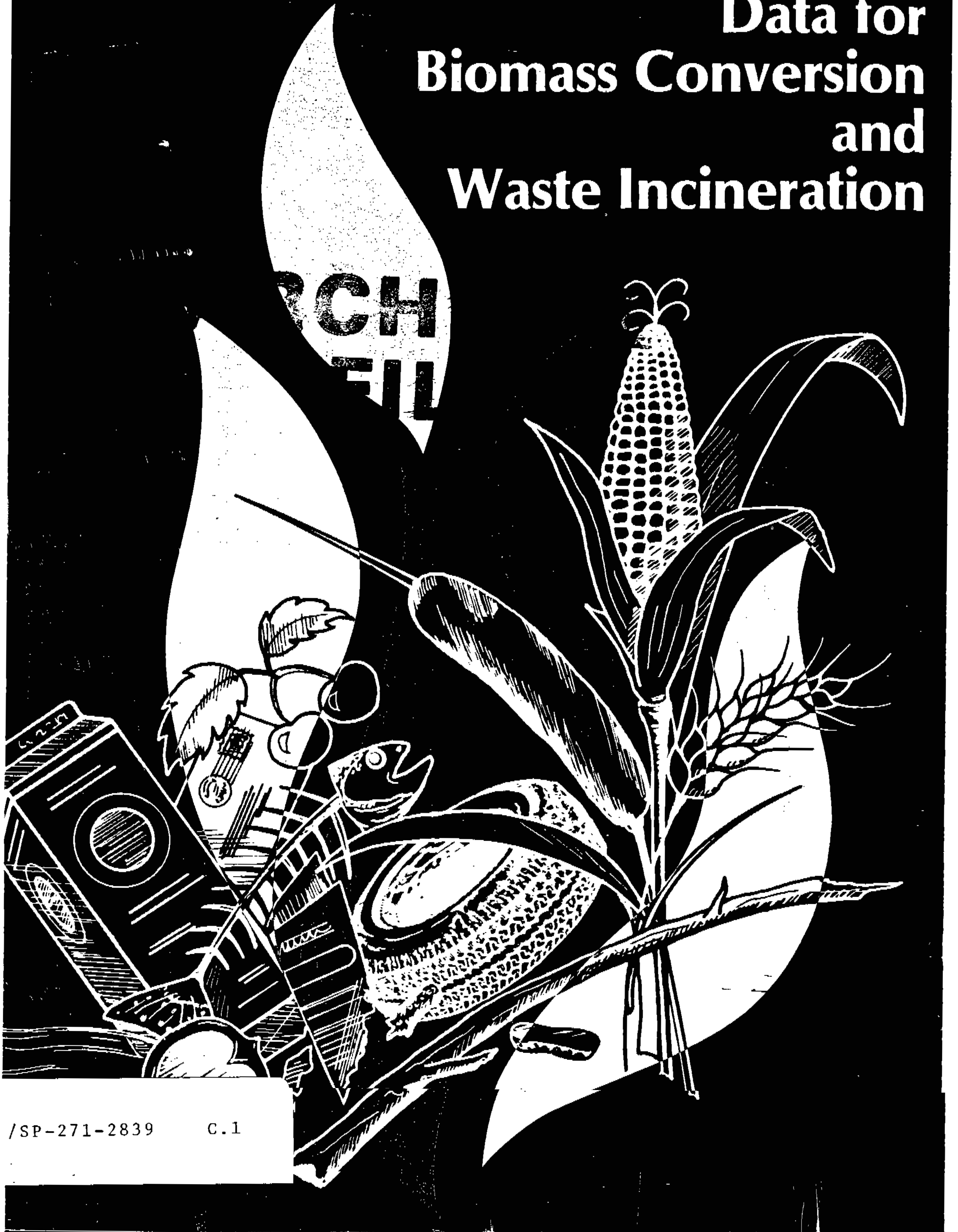
Thermodynamic Data for Biomass Conversion and Waste Incineration



Notice

Acknowledgments

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THERMODYNAMIC DATA FOR BIOMASS CONVERSION AND WASTE INCINERATION

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Preface

Incinerators have continued to play an important part in reducing the amount and modifying the type of waste discharged to the environment.

The ASME Research Committee on Industrial and Municipal Wastes was established in 1968. This committee recognized the need for greater understanding of combustion fundamentals if engineers are to design better incinerators to meet the challenge of improving the environment. It, therefore, created a subcommittee on fundamental combustion studies.

The first report of the subcommittee, *Combustion Fundamentals for Waste Incineration*, was published in 1974 [74ASM]. The purpose of the report was to help engineers make better calculations and thereby design better incinerators. The report was divided into two parts. Part one covered theoretical engineering methods of calculation and tables of equilibrium products of combustion with practical examples. Part two included the scientific theory and tables of thermodynamic properties.

In a second report of the subcommittee, *Thermodynamic Data for Waste Incineration* [78DOM/EVA], engineers were provided with thermodynamic data on materials that are mixtures of various kinds and are often difficult to describe using a single stoichiometric formula. These materials (i.e., animals, foods, plants, polymers, wood species, etc.) are encountered perhaps more often by engineers engaged in the disposal of municipal wastes than pure substances. The bulk of the data, consisting of gross heats of combustion (heating values) and specific heats, was intended to be helpful in combustion calculations.

In the eight years since the issuance of the second report, biomass and biomass wastes have joined industrial and municipal solid wastes as major sources of solid fuel. In addition, widespread applications of gasification and pyrolysis are expected to join combustion as practical conversion processes in the 1990s.

This report, under the sponsorship of the DOE Office of Renewable Technology, Biofuels and Municipal Waste Technology Division, doubles the number of materials listed, with major emphasis on different forms of biomass, both woody and agricultural. It incorporates almost all of the materials listed in *Thermodynamic Data for Waste Incineration* and now provides information for more than 600 materials.

Contents

Introduction

The general purpose of this collection of thermodynamic data of selected materials is to make property information available to the engineering community on chemical mixtures, polymers, composite materials, solid wastes, biomass, and materials not easily identifiable by a single stoichiometric formula. Workers in many sectors need this type of information: construction engineers who require thermodynamic information on materials, safety engineers assessing the hazard potential of chemicals, chemical engineers concerned with industrial unit processes, and scientists who want thermodynamic data for specific research projects.

The specific purpose of this publication is to provide engineers involved in combustion and thermochemical conversion with appropriate thermodynamic data so that they can dispose of waste materials and utilize biomass for energy in a more effective and environmentally acceptable manner. The effective disposal of waste materials is an important part of the maintenance of a high-quality environment, and combustion/thermochemical conversion offers the most significant means of volume reduction for waste materials when compared to other methods of disposal. In addition, the potential of biomass for energy is being increasingly recognized and realized.

This compilation of thermodynamic data was prepared for the Solar Energy Research Institute (SERI) by the Chemical Thermodynamics Data Center of the National Bureau of Standards. More than 700 materials have been compiled covering properties such as specific heat, gross heat of combustion, heat of fusion, heat of vaporization, and vapor pressure. The information was obtained from the master files of the NBS Chemical Thermodynamics Data Center, the annual issues of the ***Bulletin of Chemical Thermodynamics***, intermittent examinations of the *Chemical Abstracts* subject indexes, individual articles by various authors, and other general reference sources.

The compilation is organized into several broad categories; materials are listed alphabetically within each category. For each material the following are given: (1) the physical state, (2) information as to the composition or character of the material, (3) the kind of thermodynamic property reported, (4) the specific property values for the material, and (5) citations to the reference list. A name index is provided to assist a user in finding a specific material.

Several appendices are also included. Appendix A gives an empirical formula that allows heats of combustion of carbonaceous materials to be predicted with surprising accuracy when the elemental composition is known. A spread sheet illustrates this predictability with examples from this report and elsewhere. Appendix B lists some reports containing heats of combustion not included in this publication. Appendix C contains symbols, units, conversion factors, and atomic weights used in evaluating and compiling the thermodynamic data.

Units and Definitions

The notation in the tables for thermodynamic quantities follows, in general, that in *Combustion Fundamentals for Waste Incineration* [74ASM]. In those tables values were reported on a molar basis. Here, because of the lack of definite stoichiometric compositions for most of the materials included, values of the thermodynamic quantities are given on a specific basis, for one gram or one pound (unit mass) of substance. Exceptions are noted. The symbols used are briefly defined below; more extensive discussions are given in [74ASM].

Air-Drying. A process of partial drying of a sample to bring its moisture content near to equilibrium with the atmosphere in which further reduction, division, and characterization of the sample are to take place.

Air-Dry Loss. The decrease in sample mass due to air-drying. This decrease is presumed to be moisture.

Ash. The residue remaining after ignition of a sample determined by a definite prescribed procedure.

As-Received Basis. The test data calculated to the moisture condition of the sample as it arrived in the laboratory and before any laboratory processing or conditioning.

Dry Basis. The test data calculated to theoretical base of no moisture associated with the sample.

Dry, Ash-Free Basis. The test data calculated to a theoretical base of no moisture or ash associated with the sample.

Enthalpy. The enthalpy, H, is defined by the equation: $H = U + PV$, where U is the internal energy of the system, P is the pressure, and V is the volume.

Enthalpy Difference. See Heat Content.

Gross Calorific Value. See Gross Heat of Combustion.

Gross Heat of Combustion. The heat produced by combustion of one unit of substance at constant volume in an oxygen bomb calorimeter under specified conditions. The conditions are: initial oxygen pressure of 2.0-4.0 MPa (20-40 atm), final temperature of 20°-35°C (68°-95°F), products in the form of ash, liquid water, gaseous CO_2 and N_2, and dilute aqueous HCl and H_2SO_4. It is assumed that if significant quantities of metallic elements are combusted, they are converted to their oxides. In the case of materials such as coal, wood, or refuse, if small or trace amounts of metallic elements are present, they are unchanged during combustion and are part of the ash.

In accurate studies, the observed heat is corrected for side reactions and to a standard state in which all gases are at unit fugacity. For most of the data reported here, the precision of the measurements does not warrant such refinement.

Gross Heat of Reaction. The specific isothermal gross heat of reaction at the specified temperature and at constant volume, q_v(gross), is equal to $-\Delta U/M$, where ΔU is the molar change in internal energy of the process, and M is the molecular weight. Usually, the values of q_v (or ΔU) have not been converted to the standard state ($-\Delta U°/M$) [74ASM]. Some of the data are of such low precision, because of sample variability or measurement method, that this correction is impractical.

The numerical values for q_v(gross) are given in J g^{-1}, cal g^{-1}, and Btu lb^{-1}. The joule (J) is the primary SI energy unit. The calorie used is the thermochemical calorie, defined as 4.184 J. The British thermal unit used is the thermochemical Btu. Conversion factors are given in Appendix C.

Heat Content. The difference in enthalpy, for one unit mass of substance, between two temperatures, $(H_T-H_{T(ref)})/M = (q_T-q_{T(ref)})$. T(ref) is the reference temperature, usually 0 K, 273.15 K, or 298.15 K. It is specified as q_0, q_{273} or $q_{273.15}$, and $q_{298.15}$. If other than the kelvin scale is used, this is indicated as °C, °F, or °R (Rankine, T°R = 1.8 T K).

Heat of Fusion, L_f. The specific latent heat of fusion ($\Delta H_{fus}/M$) at a pressure of 101325 Pa (1 atm). The value is the heat absorbed (in J, cal, or Btu) when one unit mass of the substance goes from the solid state to the liquid state. For a pure compound, the melting occurs at a single temperature; for the complex materials considered here, the melting process may take place over a temperature range.

Heat of Sublimation, L_s. The specific latent heat of sublimation ($\Delta H_{sub}/M$). The value is the heat absorbed when one unit mass of the substance goes from the solid state to the gaseous state. The same considerations apply as for L_v.

Heat of Transition, L_t. The specific latent heat of transition ($\Delta H_{trs}/M$) at a pressure of 101325 Pa (1 atm). The value is the heat absorbed when one unit mass of the substance goes from one solid phase to another solid phase. For a pure compound, the transition occurs at a single temperature; for the complex materials considered here, the transition process may take place over a temperature range.

Heat of Vaporization, L_v. The specific latent heat of vaporization ($\Delta H_{vap}/M$). The value is the heat absorbed when one unit mass of the substance goes from the liquid state to the gaseous state. If measured calorimetrically, the value will be for a definite temperature and pressure. If derived from the vapor pressure equation through the relation $d(\ln P)/d(1/T) = -\Delta H_{vap}/R$, the value may be referred to a definite temperature and pressure, depending upon the form of the equation. With the simple form $\ln P = A-B/T$, the value refers to the midpoint of the temperature range over which the equation is valid. The value thus obtained is for one mole of gaseous species; the average molecular weight must be obtained to calculate the specific heat of vaporization: $L_v = \Delta H_{vap}/M$.

Internal Energy. When heat, q, is added or removed, and work, w, is done on or by the system, its internal energy, U, is modified according to the equation: U ◻ $q + w$.

Net Calorific Value. See Net Heat of Combustion.

Net Heat of Combustion. The heat produced by combustion of one unit of substance at atmospheric pressure under conditions such that all water in the products remains in the form of vapor. The net heat of combustion is calculated from the gross heat of combustion at 20°C (68°F) by subtracting 572 cal g^{-1} (1030 Btu lb^{-1}) of water derived from one unit mass of sample, including both the water originally present as moisture and that formed by combustion. This subtracted amount is not equal to the latent heat of vaporization of water (586 cal g^{-1} at 20°C) because the calculation also reduces the data from the gross value at constant volume to the net value at constant pressure. The appropriate factor for this reduction is 572 cal g^{-1}.

Net Heat of Reaction. The specific isothermal net heat of reaction at the specified temperature and at constant volume. q_v(net) is equal to $-\Delta U/M$, where ΔU is the molar internal energy of the process, and M is the molecular weight. This value differs from q_v(gross) in that water formed is in the gaseous state. The specific isothermal net heat of reaction at the specified temperature and at constant pressure, q_p(net), is equal to $-\Delta H/M$, where ΔH is the molar change in enthalpy of the process, and M is the molecular weight. Where possible, the values of q_p(net) have been converted to the standard state, $(-\Delta H^\circ/M)$ [74ASM]. Most of the data, though, are of such low precision, because of sample variability or measurement method, that the correction is impractical.

Proximate Analysis. The determination by prescribed methods of moisture, volatile matter, fixed carbon (by difference), and ash. Unless otherwise specified, the term proximate analysis does not include determinations of chemical elements or any determinations other than those named.

Residual Moisture. The moisture content remaining in a sample after it has been air-dried and milled down, if necessary, to an analysis sample.

Specific Heat, C_p. The change in enthalpy with temperature at constant pressure (1 atm unless otherwise specified) for one unit mass of substance. $C_p = [\partial(H/M)/\partial T]_p$. At constant volume $C_v = [\partial(U/M)/\partial T]_v$. Numerical values for C_p are given in J g^{-1} K^{-1}, cal g^{-1} K^{-1}, and Btu lb^{-1} $°F^{-1}$.

Sublimation Pressure. The saturated equilibrium pressure over the solid substance at a given temperature. Values are expressed in pascals ($Pa = N \cdot m^{-2}$) and in Torr (Torr = 133.3224 Pa). The conventional atmosphere is taken as 101325 Pa. One bar is 100,000 Pa.

Temperature. The absolute temperature, T, is based upon the International Practical Temperature Scale. Values are given in kelvins (symbol K). The Celsius ("Centigrade") scale (symbol °C) is used to indicate the temperature or temperature range for many reported measurements. It is defined as t(°C) = T(K) - 273.15. The Fahrenheit scale, provided as a convenience for many measurements, is defined as t(°F) = 1.8t(°C) + 32. Unless specifically indicated otherwise, all temperatures T involved in equations are absolute temperature (T, K).

Ultimate Analysis. The determination of the percentages of carbon, hydrogen, nitrogen, sulfur, chlorine, ash, and oxygen in a dry sample. The percentage of oxygen is usually obtained by difference between 100% and the sum of the other determined elemental analyses.

Vapor Pressure. The saturated equilibrium pressure over the liquid substance at a given temperature. Values are expressed in pascals (Pa = $N \cdot m^{-2}$) and in Torr (Torr = 133.3224 Pa). The conventional atmosphere is taken as 101325 Pa.

Volatile Concentration. The determination of the volatile concentration (VCM) as described in 85JEN/EBE differs somewhat from the procedures described in the *ASTM Standard Test Methods.* In 85JEN/EBE, the sample is placed in a covered crucible at 600°C for 6 minutes followed by heating at 950°C for 6 minutes. The loss in weight is the volatile fraction.

Volatile Matter. Those products exclusive of moisture given off by the sample as a gas or vapor determined by definite prescribed procedures. In ASTM D 3175-77, *Standard Test Method for Volatile Matter in the Analysis of Coal and Coke,* the weighed sample is placed in a covered platinum crucible at 950°C for exactly 7 minutes. The loss in weight is the volatile fraction.

Uncertainties. No attempt has been made to assess the overall uncertainty of the data included. For some substances, uncertainties are given for the values; these represent the original authors' estimates and are usually a measure of the reproducibility of their measurements. A large assigned uncertainty usually indicates a variability of sample, not a low precision of measurement.

Use of Enthalpy versus Heat. The term "heat" has been used loosely in the scientific and engineering literature in that it does not differentiate clearly between processes at constant volume (U, internal energy) and those at constant pressure (H, enthalpy). Usage of thermodynamic state functions, such as the internal energy and enthalpy, are clear and unambiguous by their definitions. When preceded by the words "gross" or "net," the word "heat" indicates specific conditions as described in various definitions.

Multiple Sources of Data. Occasionally, several references are found in the literature that report the same thermodynamic property for a particular material. The measured values are most often not equivalent, and a selection must be made as to which value is preferred. For some materials (such as coals or wood species), the values tabulated are typical values selected from a large number of results for samples of a similar nature. The selection process is based upon the personal and professional opinion of an evaluator after all property information for a material has been collected and examined. Factors taken into consideration are (1) description of the method used to carry out the measurements, (2) characterization of the material, (3) number of measurements performed, (4) treatment of the experimental data, (5) dispersion of the results, and (6) background or experience of the laboratory personnel carrying out the measurements.

Agricultural Residues

ALFALFA, SEED, STRAW; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 72.60, ash content = 7.25, and fixed carbon = 20.15. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 46.76, hydrogen = 5.40, oxygen = 40.72, nitrogen = 1.00, sulfur = 0.02, chlorine = 0.03, and residue (ash) = 6.07.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 7937 Btu lb^{-1}
q_v(gross) = 4410 cal g^{-1}
q_v(gross) = 18450 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7468 Btu lb^{-1}
q_v(net) = 4149 cal g^{-1}
q_v(net) = 17360 J g^{-1}

85JEN/EBE

ALMOND HULLS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 71.33, ash content = 5.78, and fixed carbon = 22.89. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 45.79, hydrogen = 5.36, oxygen = 40.60, nitrogen = 0.96, sulfur = 0.01, chlorine = 0.08, and residue (ash) = 7.20.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 7838 Btu lb^{-1}
q_v(gross) = 4355 cal g^{-1}
q_v(gross) = 18220 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7370 Btu lb^{-1}
q_v(net) = 4094 cal g^{-1}
q_v(net) = 17130 J g^{-1}

85JEN/EBE

ALMOND, ORCHARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 76.83, ash content = 1.63, and fixed carbon = 21.54. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 51.30, hydrogen = 5.29, oxygen = 40.90, nitrogen = 0.66, sulfur = 0.01, chlorine = 0.04, and residue (ash) = 1.80.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8609 Btu lb^{-1}
q_v(gross) = 4783 cal g^{-1}
q_v(gross) = 20010 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 8144 Btu lb^{-1}
q_v(net) = 4524 cal g^{-1}
q_v(net) = 18930 J g^{-1}

85JEN/EBE

ALMOND SHELLS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 73.45, ash content = 4.81, and fixed carbon = 21.74. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 44.98, hydrogen = 5.97, oxygen = 42.27, nitrogen = 1.16, sulfur = 0.02, and residue (ash) = 5.60.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8337 Btu lb^{-1}
q_v(gross) = 4632 cal g^{-1}
q_v(gross) = 19380 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7817 Btu lb^{-1}
q_v(net) = 4343 cal g^{-1}
q_v(net) = 18170 J g^{-1}

85JEN/EBE

BABASSU HUSKS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 79.71, ash content = 1.59, and fixed carbon = 18.70. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 50.31, hydrogen = 5.37, oxygen = 42.29, nitrogen = 0.26, sulfur = 0.04, and residue (ash) = 1.73.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8570 Btu lb^{-1}
q_v(gross) = 4761 cal g^{-1}
q_v(gross) = 19920 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 8101 Btu lb^{-1}
q_v(net) = 4500 cal g^{-1}
q_v(net) = 18830 J g^{-1}

85JEN/EBE

BARLEY STRAW; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 68.80, ash content = 10.30, and fixed carbon = 20.90. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 39.92, hydrogen = 5.27, oxygen = 43.81, nitrogen = 1.25, and residue (ash) = 9.75.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 7447 Btu lb^{-1}
q_v(gross) = 4137 cal g^{-1}
q_v(gross) = 17310 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 6987 Btu lb^{-1}
q_v(net) = 3881 cal g^{-1}
q_v(net) = 16240 J g^{-1}

85JEN/EBE

BEAN STRAW; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 75.30, ash content = 5.93, and fixed carbon = 18.77. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 42.97, hydrogen = 5.59, oxygen = 44.93, nitrogen = 0.83, sulfur = 0.01, chlorine = 0.13, and residue (ash) = 5.54.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 7511 Btu lb^{-1}
q_v(gross) = 4173 cal g^{-1}
q_v(gross) = 17460 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7021 Btu lb^{-1}
q_v(net) = 3901 cal g^{-1}
q_v(net) = 16320 J g^{-1}

85JEN/EBE

BLACK WALNUT, ORCHARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 80.69, ash content = 0.78, and fixed carbon = 18.53. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 49.80, hydrogen = 5.82, oxygen = 43.25, nitrogen = 0.22, sulfur = 0.01, chlorine = 0.05, and residue (ash) = 0.85.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8531 Btu lb^{-1}
q_v(gross) = 4739 cal g^{-1}
q_v(gross) = 19830 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 8023 Btu lb^{-1}
q_v(net) = 4457 cal g^{-1}
q_v(net) = 18650 J g^{-1}

85JEN/EBE

CABERNET SAUVIGNON GRAPES, VINEYARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 78.63, ash content = 2.17, and fixed carbon = 19.20. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 46.59, hydrogen = 5.85, oxygen = 43.90, nitrogen = 0.83, sulfur = 0.04, chlorine = 0.08, and residue (ash) = 2.71.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8187 Btu lb^{-1}
q_v(gross) = 4548 cal g^{-1}
q_v(gross) = 19030 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7675 Btu lb^{-1}
q_v(net) = 4264 cal g^{-1}
q_v(net) = 17840 J g^{-1}

85JEN/EBE

CARDINAL GRAPES, VINEYARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 78.17, ash content = 2.22, and fixed carbon = 19.61.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8264 Btu lb^{-1}
q_v(gross) = 4591 cal g^{-1}
q_v(gross) = 19210 J g^{-1}

85JEN/EBE

CHENIN BLANC GRAPES, VINEYARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 77.28, ash content = 2.51, and fixed carbon = 20.21. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 48.02, hydrogen = 5.89, oxygen = 41.93, nitrogen = 0.86, sulfur = 0.07, chlorine = 0.10, and residue (ash) = 3.13.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8230 Btu lb^{-1}
q_v(gross) = 4572 cal g^{-1}
q_v(gross) = 19130 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7718 Btu lb^{-1}
q_v(net) = 4288 cal g^{-1}
q_v(net) = 17940 J g^{-1}

85JEN/EBE

COCOA HULLS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 67.95, ash content = 8.25, and fixed carbon = 23.80. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 48.23, hydrogen = 5.23, oxygen = 33.19, nitrogen = 2.98, sulfur = 0.12, and residue (ash) = 10.25.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8191 Btu lb^{-1}
q_v(gross) = 4551 cal g^{-1}
q_v(gross) = 19040 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7731 Btu lb^{-1}
q_v(net) = 4295 cal g^{-1}
q_v(net) = 17970 J g^{-1}

85JEN/EBE

COCONUT FIBER, DUST; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 66.58, ash content = 3.72, and fixed carbon = 29.70. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 50.29, hydrogen = 5.05, oxygen = 39.63, nitrogen = 0.45, sulfur = 0.16, chlorine = 0.28, and residue (ash) = 4.14.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8626 Btu lb^{-1}
q_v(gross) = 4792 cal g^{-1}
q_v(gross) = 20050 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 8183 Btu lb^{-1}
q_v(net) = 4546 cal g^{-1}
q_v(net) = 19020 J g^{-1}

85JEN/EBE

CORN COBS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 80.10, ash content = 1.36, and fixed carbon = 18.54. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 46.58, hydrogen = 5.87, oxygen = 45.46, nitrogen = 0.47, sulfur = 0.01, chlorine = 0.21, and residue (ash) = 1.40.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8075 Btu lb^{-1}
q_v(gross) = 4486 cal g^{-1}
q_v(gross) = 18770 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7563 Btu lb^{-1}
q_v(net) = 4202 cal g^{-1}
q_v(net) = 17580 J g^{-1}

85JEN/EBE

CORN STOVER; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 75.17, ash content = 5.58, and fixed carbon = 19.25. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 43.65, hydrogen = 5.56, oxygen = 43.31, nitrogen = 0.61, sulfur = 0.01, chlorine = 0.60, and residue (ash) = 6.26.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 7593 Btu lb^{-1}
q_v(gross) = 4218 cal g^{-1}
q_v(gross) = 17650 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7107 Btu lb^{-1}
q_v(net) = 3948 cal g^{-1}
q_v(net) = 16520 J g^{-1}

85JEN/EBE

COTTON GIN TRASH; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 67.30, ash content = 17.60, and fixed carbon = 15.10. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 39.59, hydrogen = 5.26, oxygen = 36.38, nitrogen = 2.09, and residue (ash) = 16.68.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 7064 Btu lb^{-1}
q_v(gross) = 3924 cal g^{-1}
q_v(gross) = 16420 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 6604 Btu lb^{-1}
q_v(net) = 3669 cal g^{-1}
q_v(net) = 15350 J g^{-1}

85JEN/EBE

COTTON STALKS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 65.40, ash content = 17.30, and fixed carbon = 17.30. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 39.47, hydrogen = 5.07, oxygen = 39.14, nitrogen = 1.20, sulfur = 0.02, and residue (ash) = 15.10.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 6810 Btu lb^{-1}
q_v(gross) = 3783 cal g^{-1}
q_v(gross) = 15830 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 6363 Btu lb^{-1}
q_v(net) = 3535 cal g^{-1}
q_v(net) = 14790 J g^{-1}

85JEN/EBE

ENGLISH WALNUT, ORCHARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 80.82, ash content = 1.08, and fixed carbon = 18.10. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 49.72, hydrogen = 5.63, oxygen = 43.14, nitrogen = 0.37, sulfur = 0.01, chlorine = 0.06, and residue (ash) = 1.07.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8445 Btu lb^{-1}
q_v(gross) = 4692 cal g^{-1}
q_v(gross) = 19630 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7955 Btu lb^{-1}
q_v(net) = 4419 cal g^{-1}
q_v(net) = 18490 J g^{-1}

85JEN/EBE

GEWURZTRAMINER GRAPES, VINEYARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 77.27, ash content = 2.47, and fixed carbon = 20.26.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8243 Btu lb^{-1}
q_v(gross) = 4579 cal g^{-1}
q_v(gross) = 19160 J g^{-1}

85JEN/EBE

GRAPE POMACE; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 68.54, ash content = 9.48, and fixed carbon = 21.98. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 52.91, hydrogen = 5.93, oxygen = 30.41, nitrogen = 1.86, sulfur = 0.03, chlorine = 0.05, and residue (ash) = 8.81.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8750 Btu lb^{-1}
q_v(gross) = 4861 cal g^{-1}
q_v(gross) = 20340 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 8234 Btu lb^{-1}
q_v(net) = 4575 cal g^{-1}
q_v(net) = 19140 J g^{-1}

85JEN/EBE

MACADAMIA SHELLS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 75.92, ash content = 0.40, and fixed carbon = 23.68. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 54.41, hydrogen = 4.99, oxygen = 39.69, nitrogen = 0.36, sulfur = 0.01, and residue (ash) = 0.56.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 9039 Btu lb^{-1}
q_v(gross) = 5022 cal g^{-1}
q_v(gross) = 21010 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 8604 Btu lb^{-1}
q_v(net) = 4780 cal g^{-1}
q_v(net) = 20000 J g^{-1}

85JEN/EBE

MERLOT GRAPES, VINEYARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 77.47, ash content = 3.04, and fixed carbon = 19.49.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8105 Btu lb^{-1}
q_v(gross) = 4503 cal g^{-1}
q_v(gross) = 18840 J g^{-1}

85JEN/EBE

OLIVE PITS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 78.65, ash content = 3.16, and fixed carbon = 18.19. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 48.81, hydrogen = 6.23, oxygen = 43.48, nitrogen = 0.36, sulfur = 0.02, and residue (ash) = 1.10.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 9202 Btu lb^{-1}
q_v(gross) = 5112 cal g^{-1}
q_v(gross) = 21390 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 8656 Btu lb^{-1}
q_v(net) = 4809 cal g^{-1}
q_v(net) = 20120 J g^{-1}

85JEN/EBE

PEACH PITS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 79.12, ash content = 1.03, and fixed carbon = 19.85. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 53.00, hydrogen = 5.90, oxygen = 39.14, nitrogen = 0.32, sulfur = 0.05, and residue (ash) = 1.59.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8957 Btu lb^{-1}
q_v(gross) = 4976 cal g^{-1}
q_v(gross) = 20820 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 8441 Btu lb^{-1}
q_v(net) = 4689 cal g^{-1}
q_v(net) = 19620 J g^{-1}

85JEN/EBE

PEANUT HULLS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 73.02, ash content = 5.89, and fixed carbon = 21.09. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 45.77, hydrogen = 5.46, oxygen = 39.56, nitrogen = 1.63, sulfur = 0.12, and residue (ash) = 7.46.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8019 Btu lb^{-1}
q_v(gross) = 4455 cal g^{-1}
q_v(gross) = 18640 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7542 Btu lb^{-1}
q_v(net) = 4190 cal g^{-1}
q_v(net) = 17530 J g^{-1}

85JEN/EBE

PINOT NOIR GRAPES, VINEYARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 76.83, ash content = 2.71, and fixed carbon = 20.46. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 47.14, hydrogen = 5.82, oxygen = 43.03, nitrogen = 0.86, sulfur = 0.01, chlorine = 0.13, and residue (ash) = 3.01.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8196 Btu lb^{-1}
q_v(gross) = 4553 cal g^{-1}
q_v(gross) = 19050 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7684 Btu lb^{-1}
q_v(net) = 4269 cal g^{-1}
q_v(net) = 17860 J g^{-1}

85JEN/EBE

PISTACHIO SHELLS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 82.03, ash content = 1.13, and fixed carbon = 16.84. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 48.79, hydrogen = 5.91, oxygen = 43.41, nitrogen = 0.56, sulfur = 0.01, chlorine = 0.04, and residue (ash) = 1.28.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_V(gross) = 8286 Btu lb^{-1}
q_V(gross) = 4603 cal g^{-1}
q_V(gross) = 19260 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_V(net) = 7770 Btu lb^{-1}
q_V(net) = 4316 cal g^{-1}
q_V(net) = 18060 J g^{-1}

85JEN/EBE

PRUNE PITS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 76.99, ash content = 0.50, and fixed carbon = 22.51. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 49.73, hydrogen = 5.90, oxygen = 43.57, nitrogen = 0.32, and residue (ash) = 0.48.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_V(gross) = 10015 Btu lb^{-1}
q_V(gross) = 5564 cal g^{-1}
q_V(gross) = 23280 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_V(net) = 9499 Btu lb^{-1}
q_V(net) = 5277 cal g^{-1}
q_V(net) = 22080 J g^{-1}

85JEN/EBE

RIBIER GRAPES, VINEYARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 76.97, ash content = 3.03, and fixed carbon = 20.00.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8226 Btu lb^{-1}
q_v(gross) = 4570 cal g^{-1}
q_v(gross) = 19120 J g^{-1}

85JEN/EBE

RICE HULLS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 65.47, ash content = 17.86, and fixed carbon = 16.67. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 40.96, hydrogen = 4.30, oxygen = 35.86, nitrogen = 0.40, sulfur = 0.02, chlorine = 0.12, and residue (ash) = 18.34.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 6944 Btu lb^{-1}
q_v(gross) = 3858 cal g^{-1}
q_v(gross) = 16140 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 6569 Btu lb^{-1}
q_v(net) = 3650 cal g^{-1}
q_v(net) = 15270 J g^{-1}

85JEN/EBE

RICE STRAW (COLLECTED AFTER HARVEST); solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 69.33, ash content = 13.42, and fixed carbon = 17.25. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 41.78, hydrogen = 4.63, oxygen = 36.57, nitrogen = 0.70, sulfur = 0.08, chlorine = 0.34, and residue (ash) = 15.90.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 7004 Btu lb^{-1}
q_v(gross) = 3891 cal g^{-1}
q_v(gross) = 16280 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 6599 Btu lb^{-1}
q_v(net) = 3666 cal g^{-1}
q_v(net) = 15340 J g^{-1}

85JEN/EBE

RICE STRAW, WEATHERED (COLLECTED 1/2 YEAR AFTER HARVEST); solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 62.31, ash content = 24.36, and fixed carbon = 13.33. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 34.60, hydrogen = 3.93, oxygen = 35.38, nitrogen = 0.93, sulfur = 0.16, and residue (ash) = 25.00.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 6264 Btu lb^{-1}
q_v(gross) = 3480 cal g^{-1}
q_v(gross) = 14560 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 5920 Btu lb^{-1}
q_v(net) = 3289 cal g^{-1}
q_v(net) = 13760 J g^{-1}

85JEN/EBE

SAFFLOWER STRAW; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 77.05, ash content = 4.65, and fixed carbon = 18.30. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 41.71, hydrogen = 5.54, oxygen = 46.58, nitrogen = 0.62, and residue (ash) = 5.55.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8273 Btu lb^{-1}
q_v(gross) = 4596 cal g^{-1}
q_v(gross) = 19230 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7787 Btu lb^{-1}
q_v(net) = 4326 cal g^{-1}
q_v(net) = 18100 J g^{-1}

85JEN/EBE

SUGARCANE BAGASSE; solid; Nine varieties of Indian sugarcane were used. Average ash content, 3.66%; average moisture content, 4.51%. Fibers obtained from shredding cane in a laboratory shredder and washing in running water for 24 hours to remove all soluble substances. Fibers were dried at 100°-105°C (212°-221°F) to constant weight and pulverized to pass through 60 mesh sieve.

gross heat of combustion: assume value refers to room temperature and is on a moisture-free, ash-free basis. Value is an average of gross heats of combustion of nine different varieties bagasse. The uncertainty is given as two times the standard deviation of the mean.

q_v(gross) = 8188 ± 78 Btu lb^{-1}
q_v(gross) = 4549 ± 43 cal g^{-1}
q_v(gross) = 19033 ± 180 J g^{-1}

53BHA

SUGARCANE BAGASSE; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 73.78, ash content = 11.27, and fixed carbon = 14.95. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 44.80, hydrogen = 5.35, oxygen = 39.55, nitrogen = 0.38, sulfur = 0.01, chlorine = 0.12, and residue (ash) = 9.79.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 7456 Btu lb^{-1}
q_v(gross) = 4142 cal g^{-1}
q_v(gross) = 17330 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 6987 Btu lb^{-1}
q_v(net) = 3881 cal g^{-1}
q_v(net) □ 16240 J g^{-1}

85JEN/EBE

SUGARCANE BAGASSE; solid; Material is fibrous residue from sugar cane after the cane is harvested and crushed to extract the juice. Mill-run bagasse contains an average of 46%-52% moisture, 43%-52% fiber, and 2%-6% soluble solids (mostly sucrose). Substance is composed of pith (30% dry weight of cane), fiber bundles contained in pith (15% dry weight of cane), true fiber cell rind of stalk (50% dry weight of cane), and dense waxy nonfibrous epidermus (5% dry weight of cane).

gross heat of combustion: Formulas are derived from q_v(gross) of dry, ash-free fiber = 8442 Btu lb^{-1}, q_v(gross) of soluble matter called Brix = 7110 Btu lb^{-1}, average ash content = 3% of dry material, and where S denotes the sucrose and W the moisture content % bagasse.

q_v(gross) □ 8190 - 18 S - 81.9 W Btu lb^{-1}
q_v(gross) □ 4550 - 10 S - 45.5 W cal g^{-1}
q_v(gross) □ 19037 - 42 S - 190.4 W J g^{-1}

net heat of combustion: Formulas are derived from deduction of latent heat of water vapor from q_v(gross) and where S denotes sucrose and W is moisture content % bagasse.

q_v(net) = 7650 - 18 S - 86.4 W Btu lb^{-1}
q_v(net) = 4250 - 10 S - 48.0 W cal g^{-1}
q_v(net) = 17782 - 42 S - 200.8 W J g^{-1}

53PER

THOMPSON SEEDLESS GRAPES, VINEYARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 77.39, ash content = 2.25, and fixed carbon = 20.36. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 47.35, hydrogen = 5.77, oxygen = 43.32, nitrogen = 0.77, sulfur = 0.01, chlorine = 0.07, and residue (ash) = 2.71.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8325 Btu lb^{-1}
q_v(gross) = 4625 cal g^{-1}
q_v(gross) = 19350 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7821 Btu lb^{-1}
q_v(net) = 4345 cal g^{-1}
q_v(net) = 18180 J g^{-1}

85JEN/EBE

TOKAY GRAPES, VINEYARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 76.53, ash content = 2.45, and fixed carbon = 21.02. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 47.77, hydrogen = 5.82, oxygen = 42.63, nitrogen = 0.75, sulfur = 0.03, chlorine = 0.07, and residue (ash) = 2.93.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8307 Btu lb^{-1}
q_v(gross) = 4615 cal g^{-1}
q_v(gross) = 19310 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7795 Btu lb^{-1}
q_v(net) = 4331 cal g^{-1}
q_v(net) = 18120 J g^{-1}

85JEN/EBE

WALNUT SHELLS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 78.28, ash content = 0.56, and fixed carbon = 21.16. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 49.98, hydrogen = 5.71, oxygen = 43.35, nitrogen = 0.21, sulfur = 0.01, chlorine = 0.03, and residue (ash) = 0.71.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_V(gross) = 8682 Btu lb^{-1}
q_V(gross) = 4823 cal g^{-1}
q_V(gross) = 20180 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_V(net) = 8183 Btu lb^{-1}
q_V(net) = 4546 cal g^{-1}
q_V(net) = 19020 J g^{-1}

85JEN/EBE

WHEAT DUST, FOOD AND FIBER PROCESSING WASTE; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 69.85, ash content = 13.68, and fixed carbon = 16.47. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 41.38, hydrogen = 5.10, oxygen = 35.19, nitrogen = 3.04, sulfur = 0.19, and residue (ash) = 15.10.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_V(gross) = 6969 Btu lb^{-1}
q_V(gross) = 3872 cal g^{-1}
q_V(gross) = 16200 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_V(net) = 6522 Btu lb^{-1}
q_V(net) = 3623 cal g^{-1}
q_V(net) = 15160 J g^{-1}

85JEN/EBE

WHEAT STRAW; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 71.30, ash content = 8.90, and fixed carbon = 19.80. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 43.20, hydrogen = 5.00, oxygen = 39.40, nitrogen = 0.61, sulfur = 0.11, chlorine = 0.28, and residue (ash) = 11.40.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 7533 Btu lb^{-1}
q_v(gross) = 4185 cal g^{-1}
q_v(gross) = 17510 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7094 Btu lb^{-1}
q_v(net) = 3941 cal g^{-1}
q_v(net) = 16490 J g^{-1}

85JEN/EBE

ZINFANDEL GRAPES, VINEYARD PRUNINGS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 76.99, ash content = 3.04, and fixed carbon = 19.49.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8200 Btu lb^{-1}
q_v(gross) = 4555 cal g^{-1}
q_v(gross) = 19060 J g^{-1}

85JEN/EBE

α-**BRASS**; solid; chemical composition in wt.%; (sample 1): copper, 79.75%; lead, 0.003%; iron, 0.015%; nickel, 0.01%; zinc, 20.22%; (sample 2): copper, 70.42%; tin, 0.045%; lead, 0.05%; iron, 0.02%; nickel, 0.02%; zinc, 29.445%; (sample 3): copper, 65.18%; lead, 0.001%; iron, 0.002%; nickel, 0.002%; zinc, 34.815%.

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
sample 1				
298.15	77	0.0908	0.0908	0.3798
400	260	0.0940	0.0940	0.3935
500	440	0.1014	0.1014	0.4243
600	620	0.1005	0.1005	0.4205
700	800	0.1039	0.1039	0.4347
800	980	0.1056	0.1056	0.4418
sample 2				
298.15	77	0.0905	0.0905	0.3787
400	260	0.0943	0.0943	0.3946
500	440	0.1114	0.1114	0.4661
600	620	0.1011	0.1011	0.4230
700	800	0.1045	0.1045	0.4372
800	980	0.1064	0.1064	0.4452
sample 3				
298.15	77	0.0905	0.0905	0.3787
400	260	0.0941	0.0941	0.3937
500	440	0.1050	0.1050	0.4393
600	620	0.1016	0.1016	0.4251
700	800	0.1060	0.1060	0.4435
800	980	0.1091	0.1091	0.4565

67CHA/HUL

80 NICKEL-20 CHROMIUM; solid; composition: nickel, 77.4%; chromium, 19.52%; iron, 0.45%; manganese, 0.59%; silicon, 1.4%; carbon, 0.04%.

specific heat:

273-423 K (32°-302°F)

$C_p(\text{Btu lb}^{-1}\,{}^\circ\text{F}^{-1}) = 0.10191 + 4.222 \times 10^{-5}\,T$
$C_p(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.0825 + 7.6 \times 10^{-5}\,T$
$C_p(\text{J g}^{-1}\,\text{K}^{-1}) = 0.3452 + 3.18 \times 10^{-4}\,T$

423-873 K (302°-1112°F)

$C_p(\text{Btu lb}^{-1}\,{}^\circ\text{F}^{-1}) = 0.10705 + 2.578 \times 10^{-5}\,T$
$C_p(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.0952 + 4.64 \times 10^{-5}\,T$
$C_p(\text{J g}^{-1}\,\text{K}^{-1}) = 0.3983 + 1.941 \times 10^{-4}\,T$

873-1173 K (1112°-1652°F)

$C_p(\text{Btu lb}^{-1}\,{}^\circ\text{F}^{-1}) = 0.11390 + 2.567 \times 10^{-5}\,T$
$C_p(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.1021 + 4.62 \times 10^{-5}\,T$
$C_p(\text{J g}^{-1}\,\text{K}^{-1}) = 0.4271 + 1.933 \times 10^{-4}\,T$

55DOU/DEV

ALUMINUM; solid; atomic number, 13; atomic wt., 26.98154; density, 2.712 g cm^{-3} (169.3 lb ft^{-3}).

gross heat of combustion: q_p(gross) is equal to the enthalpy of combustion, $-\Delta H_c^0$ at 25°C (77°F); product of combustion is α-corundum, Al_2O_3.

$q_p(\text{gross}) = 13359\ \text{Btu lb}^{-1}$
$q_p(\text{gross}) = 7422\ \text{cal g}^{-1}$
$q_p(\text{gross}) = 31053\ \text{J g}^{-1}$

82WAG/EVA

specific heat:

temperature (K)	temperature (°F)	$C_p(\text{Btu lb}^{-1}\,{}^\circ\text{F}^{-1})$	$C_p(\text{cal g}^{-1}\,\text{K}^{-1})$	$C_p(\text{J g}^{-1}\,\text{K}^{-1})$
298	77	0.216	0.216	0.904
500	441	0.238	0.238	0.996
700	801	0.260	0.260	1.087

heat of fusion: at the melting point, 659°C (1218°F).

$L_f = 171.5\ \text{Btu lb}^{-1}$
$L_f = 95.25\ \text{cal g}^{-1}$
$L_f = 398.5\ \text{J g}^{-1}$

(more)

α-**BRASS**; solid; chemical composition in wt.%; (sample 1): copper, 79.75%; lead, 0.003%; iron, 0.015%; nickel, 0.01%; zinc, 20.22%; (sample 2): copper, 70.42%; tin, 0.045%; lead, 0.05%; iron, 0.02%; nickel, 0.02%; zinc, 29.445%; (sample 3): copper, 65.18%; lead, 0.001%; iron, 0.002%; nickel, 0.002%; zinc, 34.815%.

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
sample 1				
298.15	77	0.0908	0.0908	0.3798
400	260	0.0940	0.0940	0.3935
500	440	0.1014	0.1014	0.4243
600	620	0.1005	0.1005	0.4205
700	800	0.1039	0.1039	0.4347
800	980	0.1056	0.1056	0.4418
sample 2				
298.15	77	0.0905	0.0905	0.3787
400	260	0.0943	0.0943	0.3946
500	440	0.1114	0.1114	0.4661
600	620	0.1011	0.1011	0.4230
700	800	0.1045	0.1045	0.4372
800	980	0.1064	0.1064	0.4452
sample 3				
298.15	77	0.0905	0.0905	0.3787
400	260	0.0941	0.0941	0.3937
500	440	0.1050	0.1050	0.4393
600	620	0.1016	0.1016	0.4251
700	800	0.1060	0.1060	0.4435
800	980	0.1091	0.1091	0.4565

67CHA/HUL

80 NICKEL-20 CHROMIUM; solid; composition: nickel, 77.4%; chromium, 19.52%; iron, 0.45%; manganese, 0.59%; silicon, 1.4%; carbon, 0.04%.

specific heat:

273-423 K (32°-302°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.10191 + 4.222 \times 10^{-5}\ T$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.0825 + 7.6 \times 10^{-5}\ T$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.3452 + 3.18 \times 10^{-4}\ T$

423-873 K (302°-1112°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.10705 + 2.578 \times 10^{-5}\ T$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.0952 + 4.64 \times 10^{-5}\ T$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.3983 + 1.941 \times 10^{-4}\ T$

873-1173 K (1112°-1652°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.11390 + 2.567 \times 10^{-5}\ T$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.1021 + 4.62 \times 10^{-5}\ T$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.4271 + 1.933 \times 10^{-4}\ T$

55DOU/DEV

ALUMINUM; solid; atomic number, 13; atomic wt., 26.98154; density, 2.712 g cm^{-3} (169.3 lb ft^{-3}).

gross heat of combustion: q_p(gross) is equal to the enthalpy of combustion, $-\Delta H_c^0$ at 25°C (77°F); product of combustion is α-corundum, Al_2O_3.

$q_p(\text{gross}) = 13359\ \text{Btu lb}^{-1}$
$q_p(\text{gross}) = 7422\ \text{cal g}^{-1}$
$q_p(\text{gross}) = 31053\ \text{J g}^{-1}$

82WAG/EVA

specific heat:

temperature (K)	(°F)	$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1})$	$C_p(\text{cal g}^{-1}\ \text{K}^{-1})$	$C_p(\text{J g}^{-1}\ \text{K}^{-1})$
298	77	0.216	0.216	0.904
500	441	0.238	0.238	0.996
700	801	0.260	0.260	1.087

heat of fusion: at the melting point, 659°C (1218°F).

$L_f = 171.5\ \text{Btu lb}^{-1}$
$L_f = 95.25\ \text{cal g}^{-1}$
$L_f = 398.5\ \text{J g}^{-1}$

(more)

ALUMINUM - Continued

heat of vaporization: at the boiling point, 2441°C (4426°F).

$L_v = 4676$ Btu lb^{-1}
$L_v = 2598$ cal g^{-1}
$L_v = 10871$ J g^{-1}

vapor pressure:

temperature (°C)	(°F)	P(atm)	P(Pa)	P(psi)
1060	1940	10^{-6}	0.1	1.470×10^{-5}
1509	2748	10^{-3}	101.3	1.470×10^{-2}
1743	3169	10^{-2}	1013.3	1.470×10^{-1}
2039	3702	10^{-1}	10132.5	1.470
2441	4426	1.0	101325.	14.696

63HUL/ORR

ALUMINUM 2024-T4; solid; composition: copper, 4.5%; magnesium, 1.5%; manganese, 0.6%; aluminum, 93.4%.

specific heat: -120° to 425°C (-250° to 800°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.1933 + 1.539 \times 10^{-4}\ T - 2.260 \times 10^{-7}\ T^2 + 1.903 \times 10^{-10}\ T^3$
$C_p(\text{cal g}^{-1}\ {}^\circ\text{C}^{-1}) = 0.198 + 2.52 \times 10^{-4}\ T - 6.73 \times 10^{-7}\ T^2 + 1.11 \times 10^{-9}\ T^3$
$C_p(\text{J g}^{-1}\ {}^\circ\text{C}^{-1}) = 0.828 + 10.5 \times 10^{-4}\ T - 28.2 \times 10^{-7}\ T^2 + 4.64 \times 10^{-9}\ T^3$

58LUC/DEE

ALUMINUM 7075-T6; solid; composition: zinc, 5.5%; magnesium, 2.5%; copper, 1.5%; chromium, 0.3%.

specific heat: -120° to 425°C (-184° to 800°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.1914 + 1.505 \times 10^{-4}\ T - 1.896 \times 10^{-7}\ T^2 + 1.715 \times 10^{-10}\ T^3$
$C_p(\text{cal g}^{-1}\ {}^\circ\text{C}^{-1}) = 0.196 + 2.50 \times 10^{-4}\ T - 5.61 \times 10^{-7}\ T^2 + 1.00 \times 10^{-9}\ T^3$
$C_p(\text{J g}^{-1}\ {}^\circ\text{C}^{-1}) = 0.820 + 10.5 \times 10^{-4}\ T - 23.5 \times 10^{-7}\ T^2 + 4.18 \times 10^{-9}\ T^3$

58LUC/DEE

CADMIUM; solid; atomic number, 48; atomic wt., 112.41; density, 8.642 g cm^{-3} (539.5 lb ft^{-3}).

gross heat of combustion: q_p(gross) is equal to the enthalpy of combustion, $-\Delta H_c^0$ at 25°C (77°F); product of combustion is cadmium oxide, CdO.

q_p(gross) = 988 Btu lb^{-1}
q_p(gross) = 549 cal g^{-1}
q_p(gross) = 2297 J g^{-1}

82WAG/EVA

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
298	77	0.0552	0.0552	0.231
400	261	0.0577	0.0577	0.242
500	441	0.0603	0.0603	0.252

heat of fusion: at the melting point, 321°C (610°F).

L_f = 23.4 Btu lb^{-1}
L_f = 13.0 cal g^{-1}
L_f = 54.4 J g^{-1}

heat of vaporization: at the boiling point, 2441°C (4426°F).

L_v = 382 Btu lb^{-1}
L_v = 212 cal g^{-1}
L_v = 887 J g^{-1}

vapor pressure:

temperature (°C)	(°F)	P(atm)	P(Pa)	P(psi)
213	415	10^{-6}	0.1	1.470×10^{-5}
385	725	10^{-3}	101.3	1.470×10^{-2}
477	891	10^{-2}	1013.3	1.470×10^{-1}
597	1107	10^{-1}	10132.5	1.470
767	1413	1.0	101325.	14.696

63HUL/ORR

CHROMIUM; solid; atomic number, 24; atomic wt., 51.9961; density, 7.2 g cm^{-3} (449.5 lb ft^{-3}).

gross heat of combustion: q_p(gross) is equal to the enthalpy of combustion, $-\Delta H_c^0$ at 25°C (77°F); product of combustion is Cr_2O_3.

q_p(gross) = 4715 Btu lb^{-1}
q_p(gross) = 2619 cal g^{-1}
q_p(gross) = 10959 J g^{-1}

82WAG/EVA

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
298	77	0.107	0.107	0.449
500	441	0.123	0.123	0.515
700	801	0.128	0.128	0.538

heat of fusion: at the melting point 1903°C (3457°F).

L_f = 170 Btu lb^{-1}
L_f = 96 cal g^{-1}
L_f = 400 J g^{-1}

heat of vaporization: at the boiling point 2665°C (4829°F).

L_v = 2814 Btu lb^{-1}
L_v = 1563 cal g^{-1}
L_v = 6542 J g^{-1}

vapor pressure:

temperature (°C)	(°F)	P(atm)	P(Pa)	P(psi)
1252	2286	10^{-6}	0.1	1.470×10^{-5}
1711	3112	10^{-3}	101.3	1.470×10^{-2}
1937	3519	10^{-2}	1013.3	1.470×10^{-1}
2250	4082	10^{-1}	10132.5	1.470
2665	4829	1.0	101325.	14.696

63HUL/ORR

CONSTANTAN; solid; composition range centering on 55 wt. % copper and 45 wt. % nickel.

specific heat: values refer to specific alloy; 60 wt. % Cu and 40 wt. % Ni; the other constantans should have specific heat within 5% of the following values.

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
1	-457.6	0.000026	0.000026	0.00011
50	-369.4	0.020	0.020	0.083
100	-279.4	0.057	0.057	0.283
200	- 99.4	0.87	0.87	0.362

40KEE/KUR

COPPER; solid; atomic number, 29; atomic wt., 63.546; density, 9.92 g cm^{-3} (556.9 lb ft^{-3}).

gross heat of combustion: q_p(gross) is equal to the enthalpy of combustion, $-\Delta H_c^0$ at 25°C (77°F); product of combustion is cuprous oxide, Cu_2O.

q_p(gross) = 570.7 Btu lb^{-1}
q_p(gross) = 317.1 cal g^{-1}
q_p(gross) = 1326.6 J g^{-1}

82WAG/EVA

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
298	77	0.0922	0.0922	0.386
500	441	0.0971	0.0971	0.406
700	801	0.1018	0.1018	0.426

heat of fusion: at the melting point 1084°C (1983°F).

L_f = 88.4 Btu lb^{-1}
$L_f \cong$ 49.1 cal g^{-1}
L_f = 205.4 J g^{-1}

heat of vaporization: at the boiling point 2573°C (4663°F).

L_v = 2057 Btu lb^{-1}
$L_v \cong$ 1143 cal g^{-1}
L_v = 4780 J g^{-1}

(more)

COPPER - continued

vapor pressure:

temperature (°C)	(°F)	P(atm)	P(Pa)	P(psi)
1118	2044	10^{-6}	0.1	1.470×10^{-5}
1589	2892	10^{-3}	101.3	1.470×10^{-2}
1830	3326	10^{-2}	1013.3	1.470×10^{-1}
2142	3888	10^{-1}	10132.5	1.470
2573	4663	1.0	101325.	14.696

63HUL/ORR

HASTELLOY X; solid; composition: carbon, 0.05%-0.15%; chromium, 20.50%-23.00%; cobalt, 0.05%-2.50%; iron, 17.00%-20.00%; manganese, 1.00% max.; molybdenum, 8.00%-10.00%; silicon, 1.00% max.; tungsten, 0.2%-1.0%; remainder nickel, 42.0%-54.0%.

specific heat: 273-1373 K (32°-2012°F)

$$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.1037 + 2.4443 \times 10^{-5}\ T + 4.4886 \times 10^{-3}\ T^2 + 7.6473 \times 10^{-15}\ T^3 - 1.1710 \times 10^{-16}\ T^4 + 7.3033 \times 10^{-19}\ T^5$$

$$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.0924 + 4.438 \times 10^{-5}\ T - 2.812 \times 10^{-9}\ T^2 + 1.030 \times 10^{-11}\ T^3 - 1.885 \times 10^{-14}\ T^4 + 1.38 \times 10^{-17}\ T^5$$

$$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.3866 + 1.8569 \times 10^{-4}\ T - 1.1765 \times 10^{-8}\ T^2 + 4.310 \times 10^{11}\ T^3 - 7.887 \times 10^{-14}\ T^4 + 5.77 \times 10^{-17}\ T^5$$

heat content: 273-1373 K (32°-2012°F)

$$q_T - q_{32}\ (\text{Btu lb}^{-1}) = 0.1020\ T + 8.6309 \times 10^{-6}\ T^2 - 2.6035 \times 10^{-9}\ T^3 + 1.9119 \times 10^{-15}\ T^4 - 2.4321 \times 10^{-17}\ T^5 + 1.2172 \times 10^{-19}\ T^6 - 4.0464\ ({}^\circ\text{F})$$

$$q_T - q_{273.2}\ (\text{cal g}^{-1}) = 0.0924\ T + 2.219 \times 10^{-5}\ T^2 - 9.373 \times 10^{-9}\ T^3 + 2.575 \times 10^{-12}\ T^4 - 3.770 \times 10^{-15}\ T^5 + 2.30 \times 10^{-18}\ T^6 - 27.1429\ (\text{K})$$

$$q_T - q_{273.2}\ (\text{J g}^{-1}) = 0.3866\ T + 9.284 \times 10^{-5}\ T^2 - 3.922 \times 10^{-8}\ T^3 + 1.0774 \times 10^{-11}\ T^4 - 1.5774 \times 10^{-14}\ T^5 + 9.62 \times 10^{-18}\ T^6 - 113.5659\ (\text{K})$$

64THA/KOH

INCONEL, ANNEALED; solid; composition: carbon, 0.04 wt. %; manganese, 0.35 wt. %; silicon, 0.20 wt. %; chromium, 15 wt. %; nickel, 78 wt. %; iron, 7.00 wt. %.

specific heat: -120° to 982°C (-184° to 1800°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.0967 + 7.366 \times 10^{-5}\ T - 6.724 \times 10^{-8}\ T^2 + 2.846 \times 10^{-11}\ T^3$
$C_p(\text{cal g}^{-1}\ {}^\circ\text{C}^{-1}) = 0.099 + 1.25 \times 10^{-4}\ T - 2.09 \times 10^{-7}\ T^2 + 1.66 \times 10^{-10}\ T^3$
$C_p(\text{J g}^{-1}\ {}^\circ\text{C}^{-1}) = 0.414 + 5.23 \times 10^{-4}\ T - 8.74 \times 10^{-7}\ T^2 + 6.95 \times 10^{-10}\ T^3$

58LUC/DEE

INCONEL "X"; solid; composition: carbon, 0.04 wt. %; manganese, 0.70 wt. %; silicon, 0.30 wt. %; chromium, 15.00 wt. %; nickel, 73.00 wt. %; iron, 7.00 wt. %; niobium, 1.00 wt. %; titanium, 2.50 wt. %; aluminum, 0.9 wt. %.

specific heat: -120° to 982°C (-184° to 1800°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.09775 + 7.284 \times 10^{-5}\ T - 8.098 \times 10^{-8}\ T^2 + 3.978 \times 10^{-11}\ T^3$
$C_p(\text{cal g}^{-1}\ {}^\circ\text{C}^{-1}) = 0.100 + 1.22 \times 10^{-4}\ T - 2.50 \times 10^{-7}\ T^2 + 2.32 \times 10^{-10}\ T^3$
$C_p(\text{J g}^{-1}\ {}^\circ\text{C}^{-1}) = 0.418 + 5.10 \times 10^{-4}\ T - 10.5 \times 10^{-7}\ T^2 + 9.71 \times 10^{-10}\ T^3$

58LUC/DEE

IRON; solid; atomic number, 26; atomic wt., 55.847; density, 7.86 g cm^{-3} (490.7 lb ft^{-3}).

gross heat of combustion: q_p(gross) is equal to the enthalpy of combustion, $-\Delta H_c^0$ at 25°C (77°F); product of combustion is hematite, Fe_2O_3.

$q_p(\text{gross}) = 3175\ \text{Btu lb}^{-1}$
$q_p(\text{gross}) = 1764\ \text{cal g}^{-1}$
$q_p(\text{gross}) = 7379\ \text{J g}^{-1}$

82WAG/EVA

specific heat:

temperature (K)	(°F)	$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1})$	$C_p(\text{cal g}^{-1}\ \text{K}^{-1})$	$C_p(\text{J g}^{-1}\ \text{K}^{-1})$
298	77	0.107	0.107	0.450
500	441	0.126	0.126	0.526
700	801	0.148	0.148	0.617

heat of fusion: at the melting point 1536°C (2797°F).

$L_f = 117.0\ \text{Btu lb}^{-1}$
$L_f = 65.0\ \text{cal g}^{-1}$
$L_f = 272.0\ \text{J g}^{-1}$

(more)

IRON - Continued

heat of vaporization: at the boiling point 2875°C (5207°F).

$L_v = 2698$ Btu lb^{-1}
$L_v = 1499$ cal g^{-1}
$L_v = 6271$ J g^{-1}

vapor pressure:

temperature (°C)	(°F)	P(atm)	P(Pa)	P(psi)
1326	2419	10^{-6}	0.1	1.470×10^{-5}
1829	3324	10^{-3}	101.3	1.470×10^{-2}
2080	3776	10^{-2}	1013.3	1.470×10^{-1}
2417	4383	10^{-1}	10132.5	1.470
2875	5207	1.0	101325.	14.696

63HUL/ORR

IRON, CAST; liquid; composition of cast iron: base iron (Fe), the compound cementite (Fe_3C), and alloying elements of graphite (C) and silicon (Si), and lesser elements such as Mn, P, and S. A typical composition for ductile iron is C = 3.2%-4.2%, Si = 1.1%-3.5%, Mn = 0.3%-0.8%, P = 0.08%, S = 0.02%, and remainder Fe.

heat content: The temperature range is (~1400°-1600°C) (2600°-2900°F); T is in K; the equation applies to all cast iron and is the sum of individual heat content equations where the lesser elements are ignored. X is weight fraction of substance.

$$q_T - q_{32}\,(\text{Btu lb}^{-1}) = (0.3164T - 1.94)\,X_{Fe} + (0.3164T - 5.36)\,X_{Fe_3C} + (0.9004T + 1494.4)\,X_C + (0.3902T + 989.5)\,X_{Si}$$

$$q_T - q_{273}\,(\text{cal g}^{-1}) = (0.1758T - 1.08)\,X_{Fe} + (0.1758T - 2.98)\,X_{Fe_3C} + (0.5002T + 830.2)\,X_C + (0.2168T + 549.7)\,X_{Si}$$

$$q_T - q_{273}\,(\text{J g}^{-1}) = (0.7357T - 4.53)\,X_{Fe} + (0.7357T - 12.47)\,X_{Fe_3C} + (2.0929T + 3473.5)\,X_C + (0.9072T + 2300.1)\,X_{Si}$$

73DUC

LEAD; solid; atomic number, 82; atomic wt., 207.2; density, 11.3 g cm^{-3} (705.5 lb ft^{-3}).

gross heat of combustion: q_p(gross) is equal to the enthalpy of combustion, $-\Delta H_c^0$ at 25°C (77°F); product of combustion is PbO_2.

q_p(gross) = 576 Btu lb^{-1}
q_p(gross) = 320 cal g^{-1}
q_p(gross) = 1339 J g^{-1}

82WAG/EVA

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
298	77	0.0305	0.0305	0.128
500	441	0.0328	0.0328	0.137
600	621	0.0339	0.0339	0.142

heat of fusion: at the melting point 327.4°C (621.3°F).

L_f = 9.90 Btu lb^{-1}
L_f = 5.50 cal g^{-1}
L_f = 23.0 J g^{-1}

heat of vaporization: at the boiling point 1743°C (3169°F).

L_v = 368.0 Btu lb^{-1}
L_v = 204.4 cal g^{-1}
L_v = 855.3 J g^{-1}

vapor pressure:

temperature (°C)	(°F)	P(atm)	P(Pa)	P(psi)
615	1139	10^{-6}	0.1	1.470×10^{-5}
956	1753	10^{-3}	101.3	1.470×10^{-2}
1137	2079	10^{-2}	1013.3	1.470×10^{-1}
1388	2530	10^{-1}	10132.5	1.470
1743	3169	1.9	101325.	14.696

63HUL/ORR

MERCURY; liquid; atomic number, 80; atomic wt., 200.59; density, 13.5939 g cm^{-3} (848.667 lb ft^{-3}).

gross heat of combustion: q_p(gross) is equal to the enthalpy of combustion, $-\Delta H_c^0$ at 25°C (77°F); product of combustion is red, orthorhombic mercuric oxide, HgO.

q_p(gross) = 194.8 Btu lb^{-1}
q_p(gross) = 108.2 cal g^{-1}
q_p(gross) = 452.8 J g^{-1}

82WAG/EVA

specific heat:

temperature (K)	temperature (°F)	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
298	77	0.0333	0.0333	0.140
500	441	0.0323	0.0323	0.135
600	621	0.0323	0.0323	0.135

heat of fusion: at the melting point -38.86°C (-37.95°F).

L_f = 4.922 Btu lb^{-1}
L_f = 2.735 cal g^{-1}
L_f = 11.44 J g^{-1}

heat of vaporization: at the boiling point 356.58°C (673.84°F).

L_v = 127.16 Btu lb^{-1}
L_v = 70.644 cal g^{-1}
L_v = 295.57 J g^{-1}

vapor pressure:

temperature (°C)	temperature (°F)	P(atm)	P(Pa)	P(psi)
14.17	57.51	10^{-6}	0.1	1.470×10^{-5}
120.21	248.38	10^{-3}	101.3	1.470×10^{-2}
175.98	348.76	10^{-2}	1013.3	1.470×10^{-1}
250.78	483.40	10^{-1}	10132.5	1.470
356.58	673.84	1.0	101325.	14.696

63HUL/ORR

MONEL; solid; corrosion resistant alloy; composition: nickel, 67 wt. %; copper, 30 wt. %; iron, 1.4 wt. %; manganese, 1 wt. %.

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
1	-457.6	0.000026	0.000026	0.00011
50	-369.4	0.019	0.019	0.078
100	-279.4	0.06	0.06	0.24
200	-99.4	0.09	0.09	0.37
300	80.6	0.10	0.10	0.43

40KEE/KUR

MONEL "K"; solid; composition: nickel, 63%-70%; aluminum, 2%-4%; iron, 2.0% (maximum); silicon, 1.0% (maximum); manganese, 1.5% (maximum); carbon, 0.25% (maximum); remainder is copper.

specific heat: -120° to 982°C (-184° to 1800°F)

C_p(Btu lb^{-1} °F^{-1}) $= 0.09479 + 7.150 \times 10^{-5}\ T - 7.717 \times 10^{-8}\ T^2 + 3.549 \times 10^{-11}\ T^3$

C_p(cal g^{-1} °C^{-1}) $= 0.097 + 1.20 \times 10^{-4}\ T - 2.39 \times 10^{-7}\ T^2 + 2.07 \times 10^{-10}\ T^3$

C_p(J g^{-1} °C^{-1}) $= 0.406 + 5.02 \times 10^{-4}\ T - 10.0 \times 10^{-7}\ T^2 + 8.66 \times 10^{-10}\ T^3$

58LUC/DEE

NICKEL; solid; atomic number, 28; atomic wt., 58.69; density, 8.90 g cm^{-3} (555.6 lb ft^{-3}).

gross heat of combustion: q_p(gross) is equal to the enthalpy of combustion, $-\Delta H_c^0$ at 25°C (77°F); product of combustion is nickel oxide, NiO.

q_p(gross) = 1757 Btu lb^{-1}
q_p(gross) = 976 cal g^{-1}
q_p(gross) = 4084 J g^{-1}

84WAG/EVA

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
298	77	0.106	0.106	0.444
500	441	0.126	0.126	0.525
630	675	0.158	0.158	0.663
700	801	0.126	0.126	0.525

(more)

NICKEL - Continued

heat of fusion: at the melting point 1452°C (2626°F).

L_f = 129.1 Btu lb^{-1}
L_f = 71.7 cal g^{-1}
L_f = 300.1 J g^{-1}

heat of vaporization: at the boiling point 2886°C (5227°F).

L_v = 2761 Btu lb^{-1}
L_v = 1534 cal g^{-1}
L_v = 6418 J g^{-1}

vapor pressure:

temperature (°C)	(°F)	P(atm)	P(Pa)	P(psi)
1370	2498	10^{-6}	0.1	1.470×10^{-5}
1882	3420	10^{-3}	101.3	1.470×10^{-2}
2131	3869	10^{-2}	1013.3	1.470×10^{-1}
2444	4431	10^{-1}	10132.5	1.470
2886	5227	1.0	101325.	14.696

63HUL/ORR

STEEL, SAE-1010; solid; composition: carbon, 0.08-0.13 wt. %; manganese, 0.30-0.60 wt. %; phosphorus, 0.035 wt. % (maximum); sulfur, 0.045 wt. % (maximum).

specific heat:

-200° to 700°C (-382° to 1292°F)

$C_p(\text{Btu lb}^{-1}\ ^\circ\text{F}^{-1}) = 0.007185 + 9.739 \times 10^{-5}\ T - 1.016 \times 10^{-7}\ T^2 + 7.133 \times 10^{-11}\ T^3$
$C_p(\text{cal g}^{-1}\ ^\circ\text{C}^{-1}) = 0.0102 + 1.64 \times 10^{-4}\ T - 3.07 \times 10^{-7}\ T^2 + 4.16 \times 10^{-10}\ T^3$
$C_p(\text{J g}^{-1}\ ^\circ\text{C}^{-1}) = 0.0427 + 6.86 \times 10^{-4}\ T - 12.8 \times 10^{-7}\ T^2 + 17.4 \times 10^{-10}\ T^3$

curie temperature: 1415°F; 768°C; 1041.5 K

58LUC/DEE

STEEL, NPL NO. 19; solid; composition: carbon, 0.315%; silicon, 0.20%; manganese, 0.69%; sulfur, 0.036%; phosphorus, 0.039%; chromium, 1.09%; nickel, 0.073%; molybdenum, 0.012%; copper, 0.066%; aluminum, 0.005%; arsenic, 0.028%; remainder is iron; annealed at 860°C (1580°F); density, 7.842 g cm^{-3} at 15°C (59°F).

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
323	122	0.1153	0.1153	0.4824
400	261	0.1232	0.1232	0.5155
490	423	0.1277	0.1277	0.5343
589	601	0.1354	0.1354	0.5665
682	768	0.1471	0.1471	0.6155

59MAR/RIX

STEEL, STAINLESS; solid; En-58C (sample 1): chromium, 17.7%; nickel, 10.9%; manganese, 1.73%; En-58B (sample 2): chromium, 17.8%; nickel, 8.05%; manganese, 1.21%.

specific heat:

Sample 1 (En-58C)

60-190 K (-352° to -118°F)

$$C_p(\text{Btu lb}^{-1}\ °\text{F}^{-1}) = 0.11077 + 1.1471 \times 10^{-4}\ T + 3.1191 \times 10^{-7}\ T^2 + 1.7884 \times 10^{-9}\ T^3$$
$$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = -0.04976 + 1.7309 \times 10^{-3}\ T - 6.980 \times 10^{-6}\ T^2 + 1.043 \times 10^{-8}\ T^3$$
$$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = -0.20819 + 7.2421 \times 10^{-3}\ T - 2.9206 \times 10^{-5}\ T^2 + 4.364 \times 10^{-8}\ T^3$$

190-320 K (-118° to 116°F)

$$C_p(\text{Btu lb}^{-1}\ °\text{F}^{-1}) = 0.10922 + 6.6460 \times 10^{-5}\ T - 1.5492 \times 10^{-7}\ T^2 + 4.0758 \times 10^{-10}\ T^3$$
$$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.00635 + 8.4104 \times 10^{-4}\ T - 2.323 \times 10^{-6}\ T^2 + 2.377 \times 10^{-9}\ T^3$$
$$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.02658 + 3.5189 \times 10^{-3}\ T - 9.721 \times 10^{-6}\ T^2 + 9.946 \times 10^{-9}\ T^3$$

Sample 2 (En-58B)

60-190 K (-352° to -118°F)

$$C_p(\text{Btu lb}^{-1}\ °\text{F}^{-1}) = 0.10911 + 9.3932 \times 10^{-5}\ T + 1.9847 \times 10^{-7}\ T^2 + 1.6202 \times 10^{-9}\ T^3$$
$$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = -0.04950 + 1.6893 \times 10^{-3}\ T - 6.596 \times 10^{-6}\ T^2 + 9.449 \times 10^{-9}\ T^3$$
$$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = -0.20711 + 7.0680 \times 10^{-3}\ T - 2.7598 \times 10^{-5}\ T^2 + 3.9535 \times 10^{-8}\ T^3$$

190-320 K (-118° to 116°F)

$$C_p(\text{Btu lb}^{-1}\ °\text{F}^{-1}) = 0.10885 + 6.6472 \times 10^{-5}\ T - 1.4788 \times 10^{-7}\ T^2 + 5.1989 \times 10^{-10}\ T^3$$
$$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = -0.00345 + 9.5756 \times 10^{-4}\ T - 2.802 \times 10^{-6}\ T^2 + 3.032 \times 10^{-9}\ T^3$$
$$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = -0.01443 + 4.0064 \times 10^{-3}\ T - 1.1725 \times 10^{-5}\ T^2 + 1.2686 \times 10^{-8}\ T^3$$

66MAR

STEEL, STAINLESS 347; solid; nickel, 11.1%; chromium, 18.3%; manganese, 1.30%; silicon, 0.52%; carbon, 0.08%; remainder is iron.

specific heat: 273-1173 K (32°-1652°F)

$C_p(\mathrm{Btu\ lb^{-1}\ {}^\circ F^{-1}}) = 0.12451 + 1.894 \times 10^{-5}\,T - 7.2712/(T + 459.67)$
$C_p(\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.1158 + 3.41 \times 10^{-5}\,T - 4.04\,T^{-1}$
$C_p(\mathrm{J\ g^{-1}\ K^{-1}}) = 0.4845 + 1.427 \times 10^{-4}\,T - 16.90\,T^{-1}$

55DOU/DEV

STEEL, STAINLESS 446; solid; nickel, 0.32%; chromium, 25.58%; manganese, 0.42%; silicon, 0.68%; carbon, 0.23%; remainder is iron.

specific heat:

273-773 K (32°-932°F)

$C_p(\mathrm{Btu\ lb^{-1}\ {}^\circ F^{-1}}) = 0.10593 + 5.9667 \times 10^{-5}\,T$
$C_p(\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.0785 + 1.074 \times 10^{-4}\,T$
$C_p(\mathrm{J\ g^{-1}\ K^{-1}}) = 0.3284 + 4.494 \times 10^{-4}\,T$

873-1173 K (1112°-1652°F)

$C_p(\mathrm{Btu\ lb^{-1}\ {}^\circ F^{-1}}) = 0.1618 + 2209 \times 10^{-0.0078(0.5556T - 17.7778)}$
$C_p(\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.1618 + 2209 \times 10^{-0.0078(T-273.2)}$
$C_p(\mathrm{J\ g^{-1}\ K^{-1}}) = 0.6770 + 9242 \times 10^{-0.0078(T-273.2)}$

55DOU/DEV

TIN; solid; white; tetragonal; atomic number, 50; atomic wt., 118.71; density, 7.28 g cm^{-3} (454.5 lb ft^{-3}).

gross heat of combustion: q_p(gross) is equal to the enthalpy of combustion, $-\Delta H_c^0$ at 25°C (77°F); product of combustion is tin dioxide, SnO_2.

q_p(gross) = 2105 Btu lb^{-1}
q_p(gross) = 1169 cal g^{-1}
q_p(gross) = 4892 J g^{-1}

82WAG/EVA

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
298	77	0.0543	0.0543	0.227
400	261	0.0580	0.0580	0.243
500	441	0.0617	0.0617	0.258

heat of transition: at the transition point, 13°C (55°F) from Sn (grey cubic) to Sn (white tetragonal).

L_t = 7.6 Btu lb^{-1}
L_t = 4.2 cal g^{-1}
L_t = 17.6 J g^{-1}

heat of fusion: at the melting point, 232°C (450°F).

L_f = 25.4 Btu lb^{-1}
L_f = 14.1 cal g^{-1}
L_f = 59.0 J g^{-1}

heat of vaporization: at the boiling point, 2623°C (4753°F).

L_v = 1073 Btu lb^{-1}
L_v = 596 cal g^{-1}
L_v = 2495 J g^{-1}

vapor pressure:

temperature (°C)	(°F)	P(atm)	P(Pa)	P(psi)
1115	2039	10^{-6}	0.1	1.470×10^{-5}
1584	2883	10^{-3}	101.3	1.470×10^{-2}
1836	3337	10^{-2}	1013.3	1.470×10^{-1}
2167	3933	10^{-1}	10132.5	1.470
2623	4753	1.0	101325.	14.696

63HUL/ORR

TITANIUM, Ti-75A; solid; composition: titanium, 99.75%; iron, 0.07%; oxygen, 0.131%; nitrogen, 0.048%; carbon, 0.06%; hydrogen, 0.0068%.

specific heat: 294-1033 K (70°-1400°F)

C_p(Btu lb^{-1} °F^{-1}) $= 0.1252 - 6.725 \times 10^{-6}\ T + 4.799 \times 10^{-8}\ T^2$
C_p(cal g^{-1} K^{-1}) $= 0.1384 - 9.1526 \times 10^{-5}\ T + 1.555 \times 10^{-7}\ T^2$
C_p(J g^{-1} K^{-1}) $= 0.5791 - 3.8294 \times 10^{-4}\ T + 6.506 \times 10^{-7}\ T^2$

56LOE

TITANIUM, Ti-150A; solid; composition: titanium, 95.65%; chromium, 2.71%; iron, 1.40%; oxygen, 0.105%; nitrogen, 0.076%; carbon, 0.05%; hydrogen, 0.0092%.

specific heat: 294-1033 K (70°-1400°F)

C_p(Btu lb^{-1} °F^{-1}) $= 0.1302 - 6.725 \times 10^{-6}\ T + 4.799 \times 10^{-8}\ T^2$
C_p(cal g^{-1} K^{-1}) $= 0.1434 - 9.1526 \times 10^{-5}\ T + 1.555 \times 10^{-7}\ T^2$
C_p(J g^{-1} K^{-1}) $= 0.6000 - 3.8294 \times 10^{-4}\ T + 6.506 \times 10^{-7}\ T^2$

56LOE

WOODS METAL; solid; low melting fusible alloy; composition: tin, 12.5 wt. %; cadmium, 12.5 wt. %; lead, 25 wt. %; bismuth, 50 wt. %.

specific heat: there is a superconducting transition at 4.8 K (-450.7°F).

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
1.5	-456.7	0.0000048	0.0000048	0.00002
2	-455.8	0.000014	0.000014	0.00006
3	-454	0.000057	0.000057	0.00024
4	-452	0.00015	0.00015	0.00062
6	-448.6	0.00069	0.00069	0.0029
10	-441.4	0.0032	0.0032	0.0134
15	-432.4	0.0071	0.0071	0.0297
20	-423.4	0.0110	0.0110	0.0460

54PAR/QUA

ZINC; solid; atomic number 30; atomic wt., 65.39; density 7.14 g cm^{-3} (445.8 lb ft^{-3}).

gross heat of combustion: q_p(gross) is equal to the enthalpy of combustion, $-\Delta H_c^0$ at 25°C (77°F); product of combustion is zinc oxide, ZnO.

q_p(gross) = 2291.4 Btu lb^{-1}
q_p(gross) = 1273.0 cal g^{-1}
q_p(gross) = 5326.2 J g^{-1}

82WAG/EVA

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
298	77	0.0928	0.0928	0.388
500	441	0.100	0.100	0.419
600	621	0.104	0.104	0.434

heat of fusion: at the melting point, 321°C (610°F).

L_f = 48.6 Btu lb^{-1}
L_f = 27.0 cal g^{-1}
L_f = 113.0 J g^{-1}

heat of vaporization: at the boiling point, 2441°C (4426°F).

L_v = 760.4 Btu lb^{-1}
L_v = 422.4 cal g^{-1}
L_v = 1767.4 J g^{-1}

vapor pressure:

temperature (°C)	(°F)	P(atm)	P(Pa)	P(psi)
286	547	10^{-6}	0.1	1.470×10^{-5}
479	894	10^{-3}	101.3	1.470×10^{-2}
581	1078	10^{-2}	1013.3	1.470×10^{-1}
718	1324	10^{-1}	10132.5	1.470
911	1672	1.0	101325.	14.696

63HUL/ORR

ZIRCALOY-2; solid; composition: tin, 1.46%; iron, 0.130%; chromium, 0.080%; nickel, 0.056%; carbon, 65 ppm; oxygen, 1489 ppm; nitrogen, 40 ppm; hydrogen, 11 ppm; copper, 20 ppm; tungsten, < 20 ppm; aluminum, 40 ppm; silicon, 47 ppm; hafnium, < 125 ppm; remainder is zirconium.

specific heat:

273-908 K (32°-1175°F)

$C_p(\text{Btu lb}^{-1}\,°\text{F}^{-1}) = 0.06763 + 1.3262 \times 10^{-5}\,T$
$C_p(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.06153 + 2.3872 \times 10^{-5}\,T$
$C_p(\text{J g}^{-1}\,\text{K}^{-1}) = 0.25744 + 9.9880 \times 10^{-5}\,T$

908-1083 K (1175°-1490°F)

$C_p(\text{Btu lb}^{-1}\,°\text{F}^{-1}) = 0.08589$
$C_p(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.08589$
$C_p(\text{J g}^{-1}\,\text{K}^{-1}) = 0.35936$

1248-1323 K (1787°-1922°F)

$C_p(\text{Btu lb}^{-1}\,°\text{F}^{-1}) = 0.08548$
$C_p(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.08548$
$C_p(\text{J g}^{-1}\,\text{K}^{-1}) = 0.35765$

heat of transition: temperature range: 810°-975°C (1490°-1787°F), for the α - β transition

$L_t = 19.1\ \text{Btu lb}^{-1}$
$L_t = 10.6\ \text{cal g}^{-1}$
$L_t = 44.4\ \text{J g}^{-1}$

67ELD/DEE

ZIRCALOY-2 (LOW NICKEL); solid; composition: tin, 1.32%; iron, 0.152%; chromium, 0.99%; nickel, 10 ppm; carbon, 150 ppm; oxygen, 1380 ppm; nitrogen, 36 ppm; copper, 20 ppm; tungsten, < 40 ppm; hafnium, 60 ppm; remainder is zirconium.

specific heat:

273-843 K (32°-1058°F)

$C_p(\text{Btu lb}^{-1}\,{}^\circ\text{F}^{-1}) = 0.06843 + 1.1514 \times 10^{-5}\,T$
$C_p(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.06314 + 2.0726 \times 10^{-5}\,T$
$C_p(\text{J g}^{-1}\,\text{K}^{-1}) = 0.26418 + 8.6718 \times 10^{-5}\,T$

873-1083 K (1112°-1490°F)

$C_p(\text{Btu lb}^{-1}\,{}^\circ\text{F}^{-1}) = 0.08571$
$C_p(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.08571$
$C_p(\text{J g}^{-1}\,\text{K}^{-1}) = 0.35861$

1248-1323 K (1787°-1922°F)

$C_p(\text{Btu lb}^{-1}\,{}^\circ\text{F}^{-1}) = 0.08548$
$C_p(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.08548$
$C_p(\text{J g}^{-1}\,\text{K}^{-1}) = 0.35765$

67ELD/DEE

BARNACLE; ***Balanus cariosus*****;** solid; invertebrate animal; crustacean of the order Cirripedia.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

$q_V(\text{gross}) = 8136$ Btu lb^{-1}
$q_V(\text{gross}) = 4520$ cal g^{-1}
$q_V(\text{gross}) = 18912$ J g^{-1}

71PAI

BEETLE; ***Tenebrio molitor*****;** solid; an insect of the order Coleoptera.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

$q_V(\text{gross}) = 11365 \pm 929$ Btu lb^{-1}
$q_V(\text{gross}) = 6314 \pm 516$ cal g^{-1}
$q_V(\text{gross}) = 26418 \pm 2159$ J g^{-1}

61SLO/RIC

BIVALVE; ***Mytilus californianus*****;** solid; Invertebrate animal composed of two parts that open and shut, such as oysters and clams; mollusks.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

$q_V(\text{gross}) = 8280$ Btu lb^{-1}
$q_V(\text{gross}) = 4600$ cal g^{-1}
$q_V(\text{gross}) = 19246$ J g^{-1}

71PAI

BRACHIOPOD; ***Glottidia pyramidata*****;** solid; A class of Molluscoida having bivalve shells.

gross heat of combustion: assume values refer to room temperature and are corrected to an ash-free basis.

$q_V(\text{gross}) = 7915 \pm 3852$ Btu lb^{-1}
$q_V(\text{gross}) = 4397 \pm 2140$ cal g^{-1}
$q_V(\text{gross}) = 18396 \pm 8954$ J g^{-1}

61SLO/RIC

CATTLE; solid; results apply to total body of cattle.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

For sample of 100% protein:	For sample of 100% fat:
q_v(gross) = 9805 Btu lb^{-1}	q_v(gross) = 17098 Btu lb^{-1}
q_v(gross) = 5447 cal g^{-1}	q_v(gross) = 9499 cal g^{-1}
q_v(gross) = 22790 J g^{-1}	q_v(gross) = 39744 J g^{-1}

61STR

CHITON; *Katherina tunicata*; solid; invertebrate animal; mollusk of the order Polyplacophora.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

q_v(gross) = 8460 Btu lb^{-1}
q_v(gross) = 4700 cal g^{-1}
q_v(gross) = 19665 J g^{-1}

71PAI

CILIATE; *Tetrahymena pyriformis*; solid; Class of Protozoa characterized by presence of cilia; found in any exposed body of water.

gross heat of combustion: assume values refer to room temperature and are corrected to an ash-free basis.

q_v(gross) = 10688 ± 373 Btu lb^{-1}
q_v(gross) = 5938 ± 207 cal g^{-1}
q_v(gross) = 24845 ± 866 J g^{-1}

61SLO/RIC

CLADOCERA; *Leptodora kindtu*; solid; A group of minute, chiefly fresh-water, entomostracan crustaceans, often know as water fleas.

gross heat of combustion: assume values refer to room temperature and are corrected to an ash-free basis.

q_v(gross) = 10091 ± 1051 Btu lb^{-1}
q_v(gross) = 5605 ± 584 cal g^{-1}
q_v(gross) = 23451 ± 2443 J g^{-1}

61SLO/RIC

COPEPOD; ***Calanus helgolandicus*****;** solid; A large subclass of crustaceans mostly minute in size found in both fresh and salt water.

gross heat of combustion: assume values refer to room temperature and are corrected to an ash-free basis.

q_V(gross) = 9720 ± 355 Btu lb^{-1}
q_V(gross) = 5400 ± 197 cal g^{-1}
q_V(gross) = 22594 ± 824 J g^{-1}

61SLO/RIC

COPEPOD; ***Trigriopus californicus*****;** solid; A large subclass of crustaceans mostly minute in size and found in both fresh and salt water.

gross heat of combustion: assume values refer to room temperature and are corrected to an ash-free basis.

q_V(gross) = 9927 ± 499 Btu lb^{-1}
q_V(gross) = 5515 ± 277 cal g^{-1}
q_V(gross) = 23075 ± 1159 J g^{-1}

61SLO/RIC

FLATWORM; ***Dugesia tigrina*****;** solid; a planarian worm of the phylum Platyhelminthes.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

q_V(gross) = 11315 ± 608 Btu lb^{-1}
q_V(gross) = 6286 ± 338 cal g^{-1}
q_V(gross) = 26301 ± 1414 J g^{-1}

61SLO/RIC

FLATWORM, TERRESTRIAL; ***Bipalium keuense*****;** solid; Large worm found in the tropics, having the head end expanded into a semicircular plate.

gross heat of combustion: assume values refer to room temperature and are corrected to an ash-free basis.

q_V(gross) = 10231 ± 223 Btu lb^{-1}
q_V(gross) = 5684 ± 124 cal g^{-1}
q_V(gross) = 23782 ± 519 J g^{-1}

61SLO/RIC

FLY, CADDIS; ***Pycnopsyche guttifer*****;** solid; insects having aquatic larvae, they are included in the Neuroptera, or constitute the order Trichoptera.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

$q_V(\text{gross}) = 10271$ Btu lb^{-1}
$q_V(\text{gross}) = 5706$ cal g^{-1}
$q_V(\text{gross}) = 23874$ J g^{-1}

61SLO/RIC

GUPPIE; ***Lebistes reticulatus*****;** solid; A small top minnow of the Barbados, Trinidad, and Venezuela area; frequently kept as an aquarium fish.

gross heat of combustion: assume values refer to room temperature and are corrected to an ash-free basis.

$q_V(\text{gross}) = 10481$ Btu lb^{-1}
$q_V(\text{gross}) = 5823$ cal g^{-1}
$q_V(\text{gross}) = 24363$ J g^{-1}

61SLO/RIC

HYDRA, GREEN; ***Chlorohydra viridissima*****;** solid; Small fresh-water hydrozoan polyps that contain chlorophyll chromatophores, usually found attached to submerged objects; the body is a simple tube with a mouth at one extremity.

gross heat of combustion: assume values refer to room temperature and are corrected to an ash-free basis.

$q_V(\text{gross}) = 10312 \pm 445$ Btu lb^{-1}
$q_V(\text{gross}) = 5729 \pm 247$ cal g^{-1}
$q_V(\text{gross}) = 23970 \pm 1033$ J g^{-1}

61SLO/RIC

MITE; ***Tyroglyphus lintneri*****;** solid; Small arachnids that are parasitic in nature.

gross heat of combustion: assume values refer to room temperature and are corrected to an ash-free basis.

$q_V(\text{gross}) = 10454 \pm 803$ Btu lb^{-1}
$q_V(\text{gross}) = 5808 \pm 446$ cal g^{-1}
$q_V(\text{gross}) = 24301 \pm 1866$ J g^{-1}

61SLO/RIC

POND MURREL, TAIL; ***Channa punctatus*****;** solid; The specimens of this economically important fresh water fish were 18-20 cm (7-8 in.) in length and captured at Aligarh in northern India. Fish were filleted and musculature tissues taken from the posterior (tail) region. Concentrations of the various chemical constituents are protein = 19.739 ± (0.137)%; fat = 1.706 ± (0.146)%; water = 73.433 ± (0.523)%; ash = 1.533 ± (0.176)%; total carbohydrate = 3.587 ± (0.535)%; glycogen = 233.325 ± (9.362) mg/100 g; cholesterol = 156.823 ± (12.005) mg/g; RNA = 23.469 ± (3.855) µg/100 mg; DNA = 23.469 ± (1.113) µg/100 mg. Values in parentheses refer to standard error of the mean; each value is a mean of 12 determinations.

gross heat of combustion: assume values refer to room temperature; value is mean of 12 determinations with standard error of the mean.

q_V(gross) = 20071.8 ± 401.6 Btu lb^{-1}
q_V(gross) = 11151.0 ± 223.1 cal g^{-1}
q_V(gross) = 46655.8 ± 933.5 J g^{-1}

78MUS/JAF

POND MURREL, TRUNK; ***Channa punctatus*****;** solid; The specimens of this economically important fresh water fish were 18-20 cm (7-8 in.) in length and captured at Aligarh in northern India. Fish were filleted and musculature tissues taken from the apex of the anterior (trunk) region. Concentrations of the various chemical constituents are protein = 18.489 ± (0.406)%; fat = 1.040 ± (0.101)%; water = 76.933 ± (0.314)%; ash = 1.200 ± (0.152)%; total carbohydrate = 2.337 ± (0.898)%; glycogen = 160.366 ± (6.585) mg/100 g; cholesterol = 114.000 ± (19.425) mg/100 g; RNA = 100.672 ± (2.476) µg/100 mg; DNA = 12.213 ± (2.464) µg/100 mg. Values in parentheses refer to standard error of the mean; each value is a mean of 12 determinations.

gross heat of combustion: assume values refer to room temperature; value is mean of 12 determinations with standard error of the mean.

q_V(gross) = 17110.8 ± 476.3 Btu lb^{-1}
q_V(gross) = 9506.0 ± 264.6 cal g^{-1}
q_V(gross) = 39773.1 ± 1107.1 J g^{-1}

78MUS/JAF

SHEEP, BLOOD; solid; protein and fat composition determined on ash-free dry basis for materials from bodies of 63 sheep; mean composition: protein, 98.80%; fat, 1.20%.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 10571$ Btu lb^{-1}
$q_V(\text{gross}) = 5873$ cal g^{-1}
$q_V(\text{gross}) = 24573$ J g^{-1}

For the % fat range 0.00 to 5.80:

$q_V(\text{gross}) = [10537 + 28.49\ (\%\ \text{fat})]$ Btu lb^{-1}
$q_V(\text{gross}) = [5854 + 15.83\ (\%\ \text{fat})]$ cal g^{-1}
$q_V(\text{gross}) = [24493 + 66.23\ (\%\ \text{fat})]$ J g^{-1}

For the % protein range 94.20 to 100.00:

$q_V(\text{gross}) = [13383 - 28.49\ (\%\ \text{protein})]$ Btu lb^{-1}
$q_V(\text{gross}) = [7435 - 15.83\ (\%\ \text{protein})]$ cal g^{-1}
$q_V(\text{gross}) = [31108 - 66.23\ (\%\ \text{protein})]$ J g^{-1}

64PAL/REI

SHEEP, CARCASS; solid; protein and fat composition determined on ash-free dry basis for carcasses of 63 sheep; mean composition: protein, 40.18%; fat, 59.82%

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 14000$ Btu lb^{-1}
$q_V(\text{gross}) = 7778$ cal g^{-1}
$q_V(\text{gross}) = 32543$ J g^{-1}

For the % fat range 33.32 to 81.69:

$q_V(\text{gross}) = [9589 + 73.75\ (\%\ \text{fat})]$ Btu lb^{-1}
$q_V(\text{gross}) = [5327 + 40.97\ (\%\ \text{fat})]$ cal g^{-1}
$q_V(\text{gross}) = [22288 + 171.42\ (\%\ \text{fat})]$ J g^{-1}

For the % protein range 18.31 to 66.68:

$q_V(\text{gross}) = [16963 - 73.75\ (\%\ \text{protein})]$ Btu lb^{-1}
$q_V(\text{gross}) = [9424 - 40.97\ (\%\ \text{protein})]$ cal g^{-1}
$q_V(\text{gross}) = [39430 - 171.42\ (\%\ \text{protein})]$ J g^{-1}

64PAL/REI

SHEEP, HIDE; solid; protein and fat composition determined on ash-free dry basis for material from bodies of 63 sheep; mean composition: protein, 74.05%; fat, 25.95%.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 11651 Btu lb^{-1}
q_V(gross) = 6473 cal g^{-1}
q_V(gross) = 27083 J g^{-1}

For the % fat range 18.37 to 38.72:

q_V(gross) = [9824 + 69.25 (% fat)] Btu lb^{-1}
q_V(gross) = [5458 + 38.47 (% fat)] cal g^{-1}
q_V(gross) = [22836 + 160.96 (% fat)] J g^{-1}

For the % protein range 61.28 to 81.63:

q_V(gross) = [16749 - 69.25 (% protein)] Btu lb^{-1}
q_V(gross) = [9305 - 38.47 (% protein)] cal g^{-1}
q_V(gross) = [38932 - 160.96 (% protein)] J g^{-1}

64PAL/REI

SHEEP, INGESTA-FREE BODY; solid; protein and fat composition determined on ash-free dry basis for bodies of 63 sheep; mean composition: protein, 43.33%; fat, 56.67%.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 13790 Btu lb^{-1}
q_V(gross) = 7661 cal g^{-1}
q_V(gross) = 32054 J g^{-1}

For the % fat range 28.80 to 79.43:

q_V(gross) = [9682 + 72.45 (% fat)] Btu lb^{-1}
q_V(gross) = [5379 + 40.25 (% fat)] cal g^{-1}
q_V(gross) = [22506 + 168.41 (% fat)] J g^{-1}

For the % protein range 20.57 to 71.20:

q_V(gross) = [16929 - 72.45 (% protein)] Btu lb^{-1}
q_V(gross) = [9405 - 40.25 (% protein)] cal g^{-1}
q_V(gross) = [39351 - 168.41 (% protein)] J g^{-1}

64PAL/REI

SHEEP, VISCERA; solid; protein and fat composition determined on ash-free dry basis for viscera from bodies of 63 sheep; mean composition: protein, 33.50%; fat, 66.50%.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 14420 Btu lb^{-1}
q_v(gross) = 8011 cal g^{-1}
q_v(gross) = 33518 J g^{-1}

For the % fat range 26.62 to 87.12:

q_v(gross) = [9770 + 69.86 (% fat)] Btu lb^{-1}
q_v(gross) = [5428 + 38.81 (% fat)] cal g^{-1}
q_v(gross) = [22711 + 162.38 (% fat)] J g^{-1}

For the % protein range 12.88-73.38:

q_v(gross) = [16762 - 69.86 (% protein)] Btu lb^{-1}
q_v(gross) = [9312 - 38.81 (% protein)] cal g^{-1}
q_v(gross) = [38961 - 162.38 (% protein)] J g^{-1}

64PAL/REI

SHRIMP, BRINE; *Artenia* sp. *(nauplu)*; solid; a brachiopod crustacean.

gross heat of combustion: assume values refer to room temperature and are corrected to an ash-free basis.

q_v(gross) = 12127 ± 1553 Btu lb^{-1}
q_v(gross) = 6737 ± 863 cal g^{-1}
q_v(gross) = 28188 ± 3611 J g^{-1}

61SLO/RIC

SNAIL; *Tegula funebralis*; solid; invertebrate animal; gastropod mollusk.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

q_v(gross) = 9144 Btu lb^{-1}
q_v(gross) = 5080 cal g^{-1}
q_v(gross) = 21255 J g^{-1}

71PAI

SNAIL, AQUATIC; *Succinea ovalis*; solid; (without shell); a gastropod mollusk.

gross heat of combustion: assume values refer to room temperature and are corrected to an ash-free basis.

q_V(gross) = 9747 ± 11 Btu lb^{-1}
q_V(gross) = 5415 ± 6 cal g^{-1}
q_V(gross) = 22656± 25 J g^{-1}

61SLO/RIC

SPITBUG; *Philenus leucophthalmus*; solid; a spittle insect.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

q_V(gross) = 12532 ± 918 Btu lb^{-1}
q_V(gross) = 6962 ± 510 cal g^{-1}
q_V(gross) = 29129 ± 2134 J g^{-1}

61SLO/RIC

STARFISH; *Pisaster ochraceus*; solid; invertebrate animal; echinoderm of the order Asteroidea.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

q_V(gross) = 3798 Btu lb^{-1}
q_V(gross) = 2110 cal g^{-1}
q_V(gross) = 8828 J g^{-1}

71PAI

α-CELLULOSE, FROM LOBLOLLY PINE WOOD; *Pinus taeda*; solid; modification of cellulose which has the highest degree of polymerization; chief constituent of paper pulp: 46.70% α-cellulose [68McM]; repeating unit: $C_6H_{10}O_5$.

specific heat: 333-413 K (140°-284°F); samples were oven-dried at 100°C (212°F) for 12 hours before measurements were made.

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.2357 + 5.5 \times 10^{-4}\ T$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = -0.01708 + 9.9 \times 10^{-4}\ T$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = -0.07146 + 4.14 \times 10^{-3}\ T$

70McM

CELLULOSE; solid; Extracted wood of northern red oak (*Quercus rubra*) was divided into three major chemical components and cellulose comprised 42.86%. Material has a repeating unit of $(C_6H_{10}O_5)$. The relationship between gross heat of combustion and moisture content (MC) is given by the regression equation: $\ell n q_v(\text{Btu lb}^{-1}) = 8.9044-(0.0022)\text{MC}(\%)$.

gross heat of combustion: oven dry basis, assume room temperature, and values are reported in international British thermal units per pound, and converted below into thermochemical units.

$q_v(\text{gross}) = 7325\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4069\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 17026\ \text{J g}^{-1}$

78MUR/MAS

CELLULOSE; solid; repeating unit: $C_6H_{10}O_5$; constitutes about 60% of the composition of wood; hydrolysis can reduce cellulose to a cellobiose repeating unit, $C_{12}H_{22}O_{11}$, and ultimately to glucose, $C_6H_{12}O_6$.

gross heat of combustion: at 30°C (86°F)

from cotton linters:	from wood pulp:
$q_v(\text{gross}) = 7497\ \text{Btu lb}^{-1}$	$q_v(\text{gross}) = 7509.6\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4165.0\ \text{cal g}^{-1}$	$q_v(\text{gross}) = 4172.0\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 17426.4\ \text{J g}^{-1}$	$q_v(\text{gross}) = 17455.6\ \text{J g}^{-1}$

50JES/PRO

CELLULOSE; solid; Substance is microcrystalline and a calorimeter calibration test substance, very homogeneous, 99.81% pure, and easily pelletized. Trade name Avicel (FMC Corporation); pH = 5.5 to 7; lot 1018-152 is an acid hydrolyzed derivative of a dissolving grade of wood pulp. The % moisture of 7 samples = 4.910 ± 0.060 (sd.); average concentration of water soluble impurities (fluoride, chloride, nitrate, and sulfate) was 62.46 ppm. The formula for Avicel combustion is $C_6H_{10}O_5(c) + 6O_2(g) \rightarrow 6CO_2(g) + 5H_2O(liq)$, and formula weight = 162.1439 g/mole.

gross heat of combustion: temperature = 28°C (82°F); 9 measurements made; correction for heat of wetting was made; mean value is given with estimated uncertainty.

q_v(gross) □ 7460.17 ± 4.577 Btu lb^{-1}
q_v(gross) = 4144.54 ± 2.543 cal g^{-1}
q_v(gross) = 17340.76 ± 10.64 J g^{-1}

81COL/XIH

CELLULOSE DIACETATE; solid; repeating unit: $C_{10}H_{10}O_7$; density, 1.36 g cm^{-3} at 20°C (68°F); 0.04% ash.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) □ 8003.2 Btu lb^{-1}
q_v(gross) = 4446.2 cal g^{-1}
q_v(gross) = 18602.9 J g^{-1}

57TAV/LAM

CELLULOSE, HOLOCELLULOSE; FROM LOBLOLLY PINE WOOD; *Pinus taeda*; solid; total water-insoluble carbohydrate constituents of loblolly pine wood; 71.18% holocellulose [68McM]; repeating unit: $C_6H_{10}O_5$.

specific heat: 333-413 K (140°-284°F); samples were oven-dried at 100°C (212°F) for 12 hours before measurements were made.

C_p(Btu lb^{-1} $°\mathrm{F}^{-1}$) = $0.23558 + 5.5 \times 10^{-4}\,T$
C_p(cal g^{-1} K^{-1}) = $-0.01724 + 9.9 \times 10^{-4}\,T$
C_p(J g^{-1} K^{-1}) = $-0.07213 + 4.14 \times 10^{-3}\,T$

70McM

CELLULOSE TRIACETATE; solid; repeating unit: $C_{12}H_{16}O_8$.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) □ 8120.7 Btu lb^{-1}
q_v(gross) = 4511.5 cal g^{-1}
q_v(gross) = 18876.1 J g^{-1}

57TAV/LAM

CHARCOAL, WOOD; solid; ultimate analysis: carbon, 93.0%; hydrogen, 2.5%; nitrogen and sulfur, 1.5%; moisture, 2%; proximate analysis: fixed carbon, 89%; ash, 1%; volatile matter, 10%.

gross heat of combustion: assume values refer to room temperature.

ash free and moisture free	as received; "good commercial fuel"
q_v(gross) = 14940 Btu lb^{-1}	q_v(gross) = 14490 Btu lb^{-1}
q_v(gross) = 8300 cal g^{-1}	q_v(gross) = 8050 cal g^{-1}
q_v(gross) = 34727 J g^{-1}	q_v(gross) = 33681 J g^{-1}

55SPI

COTTON (THREAD); solid; staple fibers surrounding the seeds of various species of Gossypium; absorbent cotton is almost pure α-cellulose; $CH_{1.774}O_{0.887}$ is elemental analysis of thread used in combustion measurements.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 7290 Btu lb^{-1}	q_v(gross) = 7394 Btu lb^{-1}
q_v(gross) = 4050 cal g^{-1}	q_v(gross) = 4108 cal g^{-1}
q_v(gross) = 16945 J g^{-1}	q_v(gross) = 17188 J g^{-1}

62GOO/SCO; 70MAN/RAP

DEXTRIN; solid; general formula: $C_6H_{10}O_5$; partial hydrolysis product of starch containing a variable number of glucose units; dextrin is obtained in several different grades by heating starch for varying lengths of time over the temperature range from 170°-240°C (338°-464°F).

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 7398 Btu lb^{-1}
q_v(gross) = 4110 cal g^{-1}
q_v(gross) = 17196 J g^{-1}

55MER/WAT

FILTER PAPER, WHATMAN; solid; Material is No. 41. W. and R. Balston, has fast filter speed, and will retain coarse and gelatinous precipitates. Paper is ashless and consists of almost pure cellulose.

specific heat: mean value in temperature range 25°-75°C (77°-167°F) for four measurements.

C_p(Btu lb^{-1} °F^{-1}) = 0.217 ± 0.003
C_p(cal g^{-1} °C^{-1}) = 0.217 ± 0.003
C_p(J g^{-1} °C^{-1}) = 0.908 ± 0.013

52NEU

GLYCOGEN; solid; general formula: $C_6H_{10}O_5$; polysaccharide found in the liver and muscles of man and animals; can be hydrolyzed to glucose.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 7538 Btu lb^{-1}
q_V(gross) = 4188 cal g^{-1}
q_V(gross) = 17523 J g^{-1}

24MEI/MEY

HEMICELLULOSE; solid; Extracted wood of northern red oak (*Quercus rubra*) was divided into three major chemical components of which hemicellulose comprised 33.33%. The relationship between gross heat of combustion and moisture content (MC) is given by the regression equation: $\ln q_V(\text{Btu lb}^{-1}) = 8.8545-(0.0103)\text{MC}(\%)$.

gross heat of combustion: oven dry basis, assume values refer to room temperature; values are reported in international British thermal units per pound and converted below into thermochemical units.

q_V(gross) = 7170 Btu lb^{-1}
q_V(gross) = 3983 cal g^{-1}
q_V(gross) = 16666 J g^{-1}

78MUR/MAS

INULIN; solid; repeating unit: $C_6H_{10}O_5$; similar in physical appearance to starch except upon complete hydrolysis yields fructose instead of glucose; inulin is the chief source of fructose.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 7542 Btu lb^{-1}
q_V(gross) = 4190 cal g^{-1}
q_V(gross) = 17531 J g^{-1}

1887BER/VIE

INULIN TRIACETATE; solid; repeating unit: $C_{12}H_{16}O_8$; dried at 120°C (248°F) in vacuum over P_2O_5.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 8140 Btu lb^{-1}
q_V(gross) = 4522 cal g^{-1}
q_V(gross) = 18920 J g^{-1}

22KAR/FIO

LIGNIN; solid; Extracted wood of northern red oak (*Quercus rubra*) was divided into three major chemical components of which lignin comprised 23.81%. Material is the major noncarbohydrate constituent of wood; it is a highly polymeric substance, with a complex, cross linked, highly aromatic structure of molecular weight about 10,000 derived principally from coniferyl alcohol ($C_{10}H_{12}O_3$) by extensive condensation-polymerization. The relationship between gross heat of combustion and moisture content (MC) is given by the regression equation: $\ell n q_v(\text{Btu lb}^{-1}) = 9.0733 - (0.0030)\text{MC}(\%)$.

gross heat of combustion: oven dry basis, assume values refer to room temperature; values are reported in international British thermal units per pound and converted below into thermochemical units.

$q_v(\text{gross}) = 9111 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 5062 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 21178 \text{ J g}^{-1}$

78MUR/MAS

LIGNIN, HARDWOOD; solid; composition: carbon, 60%; hydrogen, 6%; oxygen, 34%; empirical formula: $C_{10}H_{12}O_{4.2}$. No general agreement prevails about the structure of lignin. Studies show that a dioxyphenylpropyl grouping is an important part of the polymer.

gross heat of combustion: assume values refer to room temperature.

$q_v(\text{gross}) = 10620 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 5900 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 24685 \text{ J g}^{-1}$

67RYD; 68GUL

LIGNIN, LOBLOLLY PINE WOOD; *Pinus taeda*; solid; major (29.4% lignin) [68McM] noncarbohydrate constituent of wood; functions as a natural plastic binder for cellulose fibers.

specific heat: 333-413 K (140°-284°F); samples were oven-dried at 100°C (212°F) for 12 hours before measurements were made.

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.2579 + 4.28 \times 10^{-4}\ T$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.06133 + 7.7 \times 10^{-4}\ T$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.25660 + 3.22 \times 10^{-3}\ T$

70McM

LIGNIN, SOFTWOOD; solid; composition: carbon, 64%; hydrogen, 6%; oxygen, 30%; empirical formula: $C_{10}H_{11.2}O_{3.3}$; no general agreement prevails about the structure of lignin. Studies show that a dioxyphenylpropyl grouping is an important part of the polymer.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 11340 \text{ Btu lb}^{-1}$
$q_V(\text{gross}) = 6300 \text{ cal g}^{-1}$
$q_V(\text{gross}) = 26360 \text{ J g}^{-1}$

67RYD; 68GUL

MANURE, PIG; solid; faeces from hogs; oven dried; 0% moisture.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 7704 \text{ Btu lb}^{-1}$
$q_V(\text{gross}) = 4280 \text{ cal g}^{-1}$
$q_V(\text{gross}) = 17900 \text{ J g}^{-1}$

73BAC/HAR

STARCH; solid; general formula: $C_6H_{10}O_5$; polysaccharide is widely distributed in the vegetable kingdom and is stored in all grains and tubers.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 7560 \text{ Btu lb}^{-1}$
$q_V(\text{gross}) = 4200 \text{ cal g}^{-1}$
$q_V(\text{gross}) = 17570 \text{ J g}^{-1}$

55MER/WAT

STARCH TRIACETATE; solid; repeating unit: $C_{12}H_{16}O_8$.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 8098 \text{ Btu lb}^{-1}$
$q_V(\text{gross}) = 4499 \text{ cal g}^{-1}$
$q_V(\text{gross}) = 18824 \text{ J g}^{-1}$

22KAR/FIO

SULFITE LIQUOR, SPENT; aqueous; calcium and magnesium base waste liquor from pulping of wood by sulfite process; gaseous sulfur dioxide, 2%-4%; aqueous sulfite, 2%-7%; aqueous sulfate, 2%-5%; solids, 80%-90%; also lignin sulfonate, calcium and magnesium compounds, and carbohydrates.

gross heat of combustion: assume value refers to room temperature.

55% solids non-neutralized spent liquor	fermented and stripped liquor
q_v(gross) = 8100 - 8370 Btu lb^{-1}	q_v(gross) = 8460 - 8775 Btu lb^{-1}
q_v(gross) = 4500 - 4650 cal g^{-1}	q_v(gross) = 4700 - 4875 cal g^{-1}
q_v(gross) = 18800 - 19500 J g^{-1}	q_v(gross) = 19700 - 20400 J g^{-1}

69HUL

TANNIN EXTRACT, CHESTNUT; solid; dry powder obtained from concentrated solution produced from treatment of chestnut chips with water.

specific heat: 298 K (77°F)

C_p(Btu lb^{-1} $°F^{-1}$) = 0.2889
C_p(cal g^{-1} K^{-1}) = 0.2889
C_p(J g^{-1} K^{-1}) = 1.2088

55KAN

TANNIN EXTRACT, QUEBRACHO; solid; dry extract from a wood-derived tannin; tannin obtained from *Aspidosperma quebracho* and *Quebracho lorentzi* imported as logs from Argentina.

specific heat: 298 K (77°F)

C_p(Btu lb^{-1} $°F^{-1}$) = 0.3152
C_p(cal g^{-1} K^{-1}) = 0.3152
C_p(J g^{-1} K^{-1}) = 1.3188

55KAN

XYLAN; solid; repeating unit: $C_5H_8O_4$; polysaccharide which often occurs in association with cellulose; xylose is the repeating unit; occurs in large amounts (20%-40%) in cereal straws and brans.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 7637.0 Btu lb^{-1}
q_v(gross) = 4242.8 cal g^{-1}
q_v(gross) = 17751.9 J g^{-1}

23KAR/FIO

ALMONDS; *Prunus amygdalus*; solid; 4.4% moisture.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 5632 Btu lb^{-1}
q_v(gross) = 3129 cal g^{-1}
q_v(gross) = 13092 J g^{-1}

55MER/WAT

BEANS, GREEN; solid; chemical analysis: 87.8% water, 0.26% fat, and 4.98% water soluble solids.

specific heat: 4° to -40°C (40° to -40°F); the initial freezing point = -0.9°C (30.3°F).

temperature (°C)	(°F)	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} $°C^{-1}$)	C_p(J g^{-1} $°C^{-1}$)
4.44	40	0.92	0.92	3.85
- 0.94	30.3	0.92	0.92	3.85
- 6.67	20	1.43	1.43	5.98
-12.2	10	0.82	0.82	3.43
-17.0	0	0.68	0.68	2.85
-23.3	-10	0.60	0.60	2.51
-28.9	-20	0.56	0.56	2.34
-34.4	-30	0.50	0.50	2.09
-40	-40	0.45	0.45	1.88

49STA

BEANS, NAVY, WHITE, DRY; *Phaseolus vulgaris*; solid; 11.2% moisture.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 7020 Btu lb^{-1}
q_v(gross) = 3900 cal g^{-1}
q_v(gross) = 16320 J g^{-1}

55MER/WAT

BUTTERFAT, SUMMER; solid; Three samples were measured from different sources. The oily portion of cow's milk composed of 88% of the glycerides of oleic, stearic, and palmitic acids and 6% of the glycerides of butyric, caproic, caprylic, and capric acids.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature (°C)	temperature (°F)	H°(t)-H°(-50°C) Btu lb^{-1}	H°(t)-H°(-50°C) cal g^{-1}	H°(t)-H°(-50°C) J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	17.06	9.48	39.66
0	32	43.72	24.29	101.63
25	77	89.62	49.79	208.32
50	122	117.79	65.44	273.80
55	131	122.17	67.87	283.97

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

$L_f = 44.1$ Btu lb^{-1}
$L_f = 24.5$ cal g^{-1}
$L_f = 102.5$ J g^{-1}

55RIE

BUTTERFAT, WINTER; solid; the oily portion of cow's milk composed of 88% of the glycerides of oleic, stearic, and palmitic acids and 6% of the glycerides of butyric, caproic, caprylic, and capric acids. Three samples were measured from different sources.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature (°C)	temperature (°F)	H°(t)-H°(-50°C) Btu lb^{-1}	H°(t)-H°(-50°C) cal g^{-1}	H°(t)-H°(-50°C) J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	16.24	9.02	37.74
0	32	41.85	23.25	97.28
25	77	89.50	49.72	208.03
50	122	119.93	66.63	278.78
55	131	124.24	69.02	288.78

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

$L_f = 47.3$ Btu lb^{-1}
$L_f = 26.3$ cal g^{-1}
$L_f = 110.0$ J g^{-1}

55RIE

CABBAGE; *Brassica oleracea* var. *capitata*; solid; 94.6% moisture.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 378 Btu lb^{-1}
q_v(gross) = 210 cal g^{-1}
q_v(gross) = 880 J g^{-1}

55MER/WAT

CARROTS; solid; chemical analysis: 83.1% water, 0.18% fat, and 8.71% water soluble solids. Sample was unpeeled and cubed.

specific heat: 4° to -40°C (40° to -40°F); the initial freezing point = -2.3°C (27.8°F).

temperature (°C)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} °C^{-1})	C_p(J g^{-1} °C^{-1})
4.44	40	0.94	0.94	3.93
-2.33	27.8	0.94	0.94	3.93
-6.67	20	2.11	2.11	8.83
-12.2	10	0.98	0.98	4.10
-17.0	0	0.73	0.73	3.05
-23.3	-10	0.58	0.58	2.43
-28.9	-20	0.48	0.48	2.01
-34.4	-30	0.40	0.40	1.67
-40	-40	0.34	0.34	1.42

49STA

CAULIFLOWER; solid; chemical analysis: 92.0% water, 0.14% fat, and 3.64% water soluble solids. Sample contained no leafy material.

specific heat: 4° to -40°C (40° to -40°F); the initial freezing point = -1.1°C (30.0°F).

temperature (°C)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} °C^{-1})	C_p(J g^{-1} °C^{-1})
4.44	40	0.73	0.73	3.05
-1.11	30.0	0.73	0.73	3.05
-6.67	20	1.75	1.75	7.32
-12.2	10	0.82	0.82	3.43
-17.0	0	0.66	0.66	2.76
-23.3	-10	0.58	0.58	2.42
-28.9	-20	0.52	0.52	2.18
-34.4	-30	0.48	0.48	2.01
-40	-40	0.45	0.45	1.88

49STA

CITRUS FRUIT, RINDS AND SEEDS; solid; ultimate analysis: carbon, 44.11%; hydrogen, 5.22%; oxygen, 38.34%; nitrogen, 1.02%; sulfur, 0.11%; ash, 3.18%; moisture, 8.02%; proximate analysis as received: moisture, 8.02%; volatile matter, 71.46%; fixed carbon, 17.34%; ash, 3.18%.

gross heat of combustion: assume values refer to room temperature.

as received	air dried
q_V(gross) = 1708 Btu lb^{-1}	q_V(gross) = 7376 Btu lb^{-1}
q_V(gross) = 949 cal g^{-1}	q_V(gross) = 4098 cal g^{-1}
q_V(gross) = 3970 J g^{-1}	q_V(gross) = 17146 J g^{-1}

66KAI; 68KAI/FRI

COCOA BUTTER; solid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 194. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 38.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature (°C)	(°F)	H°(t)-H°(-50°C) Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	14.67	8.15	34.10
0	32	33.10	18.39	76.94
25	77	63.76	35.42	148.20
50	122	131.85	73.25	306.47
55	131	136.22	75.68	316.65

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 63.0 Btu lb^{-1}
L_f = 36.0 cal g^{-1}
L_f = 146.4 J g^{-1}

55RIE

COCONUT; *Cocos nucifera*; solid; meat; 19.2% moisture.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 4882 Btu lb^{-1}
q_V(gross) = 2712 cal g^{-1}
q_V(gross) = 11347 J g^{-1}

55MER/WAT

CORN (MAIZE), GREEN; *Zea mays*; solid; 76.0% moisture.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 2002 Btu lb^{-1}
q_v(gross) = 1112 cal g^{-1}
q_v(gross) = 4653 J g^{-1}

55MER/WAT

COWPEAS; *Vigna sinesis*; solid; 10.0% moisture.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 7200 Btu lb^{-1}
q_v(gross) = 4000 cal g^{-1}
q_v(gross) = 16736 J g^{-1}

55MER/WAT

CUCUMBERS; solid; chemical analysis: 96.1% water, 0.07% fat, and 1.63% water soluble solids. Sample was unpeeled and cubed.

specific heat: 4° to -40°C (40° to -40°F); the initial freezing point = -0.6°C (31.0°F).

temperature (°C)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} °C^{-1})	C_p(J g^{-1} °C^{-1})
4.44	40	0.92	0.92	3.85
- 0.56	31.0	0.92	0.92	3.85
- 6.67	20	1.32	1.32	5.52
-12.2	10	0.70	0.70	2.93
-17.0	0	0.58	0.58	2.43
-23.3	-10	0.53	0.53	2.22
-28.9	-20	0.49	0.49	2.05
-34.4	-30	0.48	0.48	2.01
-40	-40	0.45	0.45	1.88

49STA

EGG ALBUMIN; solid; a crystallizable protein; molecular weight about 33,800; from egg white.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) □ 10280 Btu lb^{-1}
q_v(gross) □ 5710 cal g^{-1}
q_v(gross) = 23891 J g^{-1}

specific heat: temperature range: 273-298 K (32°-77°F); anhydrous.

C_p(Btu lb^{-1} °F^{-1}) = 0.267
C_p(cal g^{-1} K^{-1}) = 0.267
C_p(J g^{-1} K^{-1}) = 1.117

55MER/WAT; 72BER/KLI

EGG YOLK; solid; yellow, semi-solid material of an egg; specific gravity, 0.95; high cholesterol content.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) □ 10510 Btu lb^{-1}
q_v(gross) □ 5840 cal g^{-1}
q_v(gross) = 24435 J g^{-1}

55MER/WAT

FAT, ANIMAL; solid; mixture of glycerides of fatty acids.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 17100 Btu lb^{-1}
q_v(gross) □ 9500 cal g^{-1}
q_v(gross) = 39750 J g^{-1}

55MER/WAT

FAT, BARLEY; solid; ether extracted.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 16330 Btu lb^{-1}
q_v(gross) = 9070 cal g^{-1}
q_v(gross) = 37950 J g^{-1}

55MER/WAT

FAT, BEEF; solid.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 17100$ Btu lb^{-1}
$q_V(\text{gross}) = 9500$ cal g^{-1}
$q_V(\text{gross}) = 39750$ J g^{-1}

fat obtained by ether extraction

$q_V(\text{gross}) = 16630$ Btu lb^{-1}
$q_V(\text{gross}) = 9240$ cal g^{-1}
$q_V(\text{gross}) = 38660$ J g^{-1}

55MER/WAT

FAT, BUTTER; solid; processed from cream of cow's milk; composed mainly of glycerides (90%) of oleic, palmitic, and stearic acids; remainder (10%) is made up of glycerides of butyric, capric, caprylic, and caproic acids. Saponification number 210-230.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 16690$ Btu lb^{-1}
$q_V(\text{gross}) = 9270$ cal g^{-1}
$q_V(\text{gross}) = 38785$ J g^{-1}

55MER/WAT

FAT, FRIED; solid; ultimate analysis: carbon, 73.14%; hydrogen, 11.54%; oxygen, 14.28%; nitrogen, 0.43%; sulfur, 0.07%; ash, 0.00%; proximate analysis as received: moisture, 0.00%; volatile matter, 97.64%; fixed carbon, 2.36%; ash, 0.00%.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 16480$ Btu lb^{-1}
$q_V(\text{gross}) = 9154$ cal g^{-1}
$q_V(\text{gross}) = 38300$ J g^{-1}

66KAI

FAT, LARD; liquid; Material was extracted from animal fats to form a commercial lard and the acid value was 0.33 mg KOH/g. Specific gravity (15/15°C) = 0.9145. Fatty acids found in the oil: capric, 0.18%; lauric, 0.11%; myristic, 1.52%; palmitic, 23.73%; palmitoleic, 3.35%; stearic, 15.16%; oleic, 45.42%; linoleic, 8.81%; linolenic, 0.51%; and eiconsenoic, 0.74%.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 17136$ Btu lb^{-1}
$q_V(\text{gross}) = 9520$ cal g^{-1}
$q_V(\text{gross}) = 39832$ J g^{-1}

75KOM/DAN

FAT, LARD; solid; purified internal fat of the hog; fatty acid composition (typical): myristic, 1.1%; palmitic, 30.4%; stearic, 17.9%; oleic, 41.2%; linoleic, 5.7%. Iodine number 46-66.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 17260 Btu lb^{-1}
q_v(gross) = 9590 cal g^{-1}
q_v(gross) = 40120 J g^{-1}

55MER/WAT

FAT, MUTTON; solid.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 17120 Btu lb^{-1}
q_v(gross) = 9510 cal g^{-1}
q_v(gross) = 39790 J g^{-1}

fat obtained by ether extraction

q_v(gross) = 16780 Btu lb^{-1}
q_v(gross) = 9320 cal g^{-1}
q_v(gross) = 39000 J g^{-1}

55MER/WAT

FAT, OAT; *Avena sativa*; solid; ether extract.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 16330 Btu lb^{-1}
q_v(gross) = 9070 cal g^{-1}
q_v(gross) = 37950 J g^{-1}

55MER/WAT

FAT, PORK; solid.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 17100 Btu lb^{-1}
q_v(gross) = 9500 cal g^{-1}
q_v(gross) = 39750 J g^{-1}

fat obtained by ether extraction

q_v(gross) = 16430 Btu lb^{-1}
q_v(gross) = 9130 cal g^{-1}
q_v(gross) = 38200 J g^{-1}

55MER/WAT

FAT, RYE; *Secale cereale*; solid; ether extract.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 16240 Btu lb^{-1}
q_v(gross) = 9020 cal g^{-1}
q_v(gross) = 37740 J g^{-1}

55MER/WAT

FAT, WHEAT; *Triticum aestivum*; solid; ether extract.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 16330 Btu lb^{-1}
q_v(gross) = 9070 cal g^{-1}
q_v(gross) = 37950 J g^{-1}

55MER/WAT

FLOUR, SOY BEAN; *Soia hispida.*

gross heat of combustion: assume values refer to room temperature.

4.17% moisture, 6.5% fat	6.5% moisture, 3.3% fat
q_v(gross) = 6689 Btu lb^{-1}	q_v(gross) = 6264 Btu lb^{-1}
q_v(gross) = 3716 cal g^{-1}	q_v(gross) = 3480 cal g^{-1}
q_v(gross) = 15548 J g^{-1}	q_v(gross) = 14560 J g^{-1}

55MER/WAT

FLOUR, WHEAT; solid; the finely ground and bolted meal of wheat, *Triticum aestivum*; density, 0.73 g cm^{-3}.

net heat of explosion: nonisothermal in air; temperature ~250°C (482°F).

$q_p(net) = 333$ Btu lb^{-1}
$q_p(net) = 185$ cal g^{-1}
$q_p(net) = 774$ J g^{-1}

specific heat: 100°-250°C (212°-482°F)

$C_p(Btu\ lb^{-1}\ °F^{-1}) = 0.5$
$C_p(cal\ g^{-1}\ K^{-1}) = 0.5$
$C_p(J\ g^{-1}\ K^{-1}) = 2.1$

gross heat of combustion: assume values refer to room temperature.

graham, whole grain; 10.5% moisture

$q_v(gross) = 7207$ Btu lb^{-1}
$q_v(gross) = 4004$ cal g^{-1}
$q_v(gross) = 16750$ J g^{-1}

semolina; 7.57% moisture

$q_v(gross) = 7488$ Btu lb^{-1}
$q_v(gross) = 4160$ cal g^{-1}
$q_v(gross) = 17405$ J g^{-1}

standard patent; 10.3% moisture

$q_v(gross) = 7218$ Btu lb^{-1}
$q_v(gross) = 4010$ cal g^{-1}
$q_v(gross) = 16780$ J g^{-1}

55MER/WAT; 69ABR/ABR

FOOD WASTES, VEGETABLE; solid; ultimate analysis: carbon, 49.06%; hydrogen, 6.62%; oxygen, 37.55%; nitrogen, 1.68%; sulfur, 0.20%; ash, 4.8%; proximate analysis as received: moisture, 78.29%; volatile matter, 17.10%; fixed carbon, 3.55%; ash, 1.06%.

gross heat of combustion: assume values refer to room temperature.

as received

$q_v(gross) = 1796$ Btu lb^{-1}
$q_v(gross) = 998$ cal g^{-1}
$q_v(gross) = 4175$ J g^{-1}

dry basis

$q_v(gross) = 8276$ Btu lb^{-1}
$q_v(gross) = 4598$ cal g^{-1}
$q_v(gross) = 19236$ J g^{-1}

66KAI

GELATIN; solid; an albumin type protein belonging to the scleroprotein class with the questionable formula $C_{76}H_{124}O_{29}N_{24}S$. It occurs in bones and fibrous animal tissue in the form of its anhydride collagen, which is converted into gelatin upon boiling with dilute acids. It is particularly rich in glycine and lycine.

heat of solution: the value is for the material at 25°C (77°F) dissolved in the acid mixture at 75°C (167°F); the result is the average of 5 determinations. The acid mixture contained 5% by weight of HF and 19.95% by weight HCl.

$\Delta_{sol}H = 19.13 \pm 0.58$ Btu lb^{-1}
$\Delta_{sol}H = 10.63 \pm 0.32$ cal g^{-1}
$\Delta_{sol}H = 44.48 \pm 1.34$ J g^{-1}

52NEU

GRAPES, THOMPSON SEEDLESS; solid; chemical analysis: 81.4% water, 0.26% fat, and 15.6% water soluble solids. Sample was whole with short stem.

specific heat: 4° to -40°C (40° to -40°F); no freezing point was observed.

temperature (°C)	temperature (°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} °C^{-1})	C_p(J g^{-1} °C^{-1})
4.44	40	0.89	0.89	3.72
- 6.67	20	3.84	3.84	16.07
-12.2	10	1.49	1.49	6.23
-17.0	0	0.95	0.95	3.98
-23.3	-10	0.75	0.75	3.14
-28.9	-20	0.62	0.62	2.59
-34.4	-30	0.56	0.56	2.34
-40	-40	0.52	0.52	2.18

49STA

GROATS, SUN IX; solid; Grain has fat content of 8.1%. The relationship between the grain and the moisture content was determined. One third of the samples were not conditioned, one third were conditioned by adding distilled water and equilibrating for one week, and the rest were dried in a vacuum over $CaCl_2$ until they reached their respective moisture contents. Moisture content was determined by drying triplicate ground samples in a ventilated oven at 113°C (235°F) for 4 hours.

specific heat: straight line regression equations for the relation between the specific heat and moisture content where C_p is apparent specific heat and M is moisture content (%). The apparent specific heat of water $[C_p(w)]$ was calculated from the equation.

$C_p = 0.0119\ M + 0.257\ \text{Btu lb}^{-1}\ °\text{F}^{-1}$
$C_p = 0.0119\ M + 0.257\ \text{cal g}^{-1}\ \text{K}^{-1}$
$C_p = 0.0498\ M + 1.075\ \text{J g}^{-1}\ \text{K}^{-1}$

$C_p(w) = 1.447\ \text{Btu lb}^{-1}\ °\text{F}^{-1}$
$C_p(w) = 1.447\ \text{cal g}^{-1}\ \text{K}^{-1}$
$C_p(w) = 6.054\ \text{J g}^{-1}\ \text{K}^{-1}$

54HAS

HERRING OIL; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 193. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 120.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature			H°(t)-H°(-50°C)	
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	21.38	11.88	49.71
0	32	51.14	28.41	118.87
25	77	79.81	44.34	185.52
50	122	100.98	56.10	234.72
55	131	105.25	58.47	244.64

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

$L_f = 22.1\ \text{Btu lb}^{-1}$
$L_f = 12.3\ \text{cal g}^{-1}$
$L_f = 51.5\ \text{J g}^{-1}$

55RIE

HOMINY; from corn (maize); *Zea mays*; 10.96% moisture.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 7175 Btu lb^{-1}
q_v(gross) = 3986 cal g^{-1}
q_v(gross) = 16677 J g^{-1}

55MER/WAT

HONEYDEW MELON; solid; chemical analysis: 92.6% water, 0.21% fat, and 2.83% water soluble solids. Sample was cubed, seeds included, no rind.

specific heat: 4° to -40°C (40° to -40°F); the initial freezing point = -0.8°C (30.5°F).

temperature (°C)	(°F)	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} $°C^{-1}$)	C_p(J g^{-1} $°C^{-1}$)
4.44	40	0.92	0.92	3.85
- 0.83	30.5	0.92	0.92	3.85
- 6.67	20	1.85	1.85	7.74
-12.2	10	0.94	0.94	3.93
-17.0	0	0.68	0.68	2.85
-23.3	-10	0.58	0.58	2.43
-28.9	-20	0.53	0.53	2.22
-34.4	-30	0.50	0.50	2.09
-40	-40	0.48	0.48	2.01

49STA

LARD, AMERICAN COMMERCIAL; solid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 202. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 66.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature			H°(t)-H°(-50°C)	
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	16.67	9.26	38.74
0	32	48.98	27.21	113.85
25	77	88.54	49.19	205.81
50	122	120.33	66.85	279.70
55	131	124.70	69.28	289.87

heat of fusion: results is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 47.7 Btu lb^{-1}
L_f = 26.5 cal g^{-1}
L_f = 110.9 J g^{-1}

55RIE

LARD, GERMAN COMMERCIAL; solid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule ⊟ 202. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 49.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	15.73	8.74	36.57
0	32	41.40	23.00	96.23
25	77	78.12	43.40	181.59
50	122	122.90	68.28	285.68
55	131	127.51	70.84	296.39

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 52.6 Btu lb^{-1}
L_f = 29.2 cal g^{-1}
L_f = 122.2 J g^{-1}

55RIE

MALTING BARLEY; solid; Grain was heavily husked; sample (A) was as harvested from field (germination was 100%), sample (B) was wetted by addition of water or water vapor, and sample (C) was dried in a vacuum at 30°C (86°F).

specific heat: temperature range 273-291 K (32°-64°F), data are mean values with standard error in parentheses and moisture content (M) on a wet weight basis.

Sample	M %	C_p (Btu lb^{-1} $°F^{-1}$)	C_p (cal g^{-1} K^{-1})	C_p (J g^{-1} K^{-1})
A	13.8	0.387(0.0026)	0.387(0.0026)	1.619(0.0109)
B	16.5	0.436(0.0026)	0.436(0.0026)	1.824(0.0109)
C	9.4	0.359(0.0016)	0.359(0.0016)	1.502(0.0067)

54DIS

MARGARINE, TABLE; solid; a butter substitute, an emulsion of fats in milk serum, (the oleo margarine is the liquid fat from which margarine is made by hydrogenation). Two samples were used from different sources.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	16.70	9.28	38.83
0	32	43.20	24.00	100.42
25	77	83.95	46.64	195.14
50	122	119.05	66.14	276.73
55	131	123.46	68.59	286.98

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 46.4 Btu lb^{-1}
L_f = 25.8 cal g^{-1}
L_f = 107.9 J g^{-1}

55RIE

MARGARINE, COMMERCIAL; solid; a butter substitute which is an emulsion of fats in milk serum, (the oleomargarine is the liquid fat from which margarine is made by hydrogenation). Three samples were used from different sources.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	16.16	8.98	37.57
0	32	45.04	25.02	104.68
25	77	91.08	50.60	211.71
50	122	121.43	67.46	282.25
55	131	125.86	69.92	292.55

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 47.5 Btu lb^{-1}
L_f = 26.4 cal g^{-1}
L_f = 110.5 J g^{-1}

55RIE

MEAL, CORN (MAIZE); *Zea mays*; 11.79% moisture.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 6881 Btu lb^{-1}
q_v(gross) = 3823 cal g^{-1}
q_v(gross) = 15995 J g^{-1}

55MER/WAT

MEAT, COOKED SCRAPS; solid; ultimate analysis: carbon, 59.59%; hydrogen, 9.47%; oxygen, 24.65%; nitrogen, 1.02%; sulfur, 0.19%; ash, 5.08%; proximate analysis as received: moisture, 38.74%; volatile matter, 56.34%; fixed carbon, 1.81%; ash, 3.11%.

gross heat of combustion: assume values refer to room temperature.

as received	dry basis
q_v(gross) = 7628 Btu lb^{-1}	q_v(gross) = 12450 Btu lb^{-1}
q_v(gross) = 4238 cal g^{-1}	q_v(gross) = 6917 cal g^{-1}
q_v(gross) = 17731 J g^{-1}	q_v(gross) = 28942 J g^{-1}

66KAI

OATS; *Avena sativa*; solid; rolled; 8.66% moisture.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 8208 Btu lb^{-1}
q_v(gross) = 4560 cal g^{-1}
q_v(gross) = 19080 J g^{-1}

55MER/WAT

OATS, SUN II; solid; Grain has fat content of 4.5%. The relationship between the grain and the moisture content was determined. One third of the samples were not conditioned, one third were conditioned by adding distilled water and equilibrating for one week, and the rest were dried in a vacuum over $CaCl_2$ until they reached their respective moisture contents. Moisture content was determined by drying triplicate ground samples in a ventilated oven at 113°C (235°F) for 4 hours.

specific heat: straight line regression equations for the relation between the specific heat and moisture content where C_p is apparent specific heat and M is moisture content (%). The apparent specific heat of water $[C_p(w)]$ was calculated from the equation for M = 100%.

$C_p = 0.0078\ M + 0.305\ \text{Btu lb}^{-1}\ °\text{F}^{-1}$
$C_p = 0.0078\ M + 0.305\ \text{cal g}^{-1}\ \text{K}^{-1}$
$C_p = 0.0326\ M + 1.276\ \text{J g}^{-1}\ \text{K}^{-1}$

$C_p(w) = 1.085\ \text{Btu lb}^{-1}\ °\text{F}^{-1}$
$C_p(w) = 1.085\ \text{cal g}^{-1}\ \text{K}^{-1}$
$C_p(w) = 4.540\ \text{J g}^{-1}\ \text{K}^{-1}$

54HAS

PEANUT BUTTER, HARDENED; solid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 189. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 78. Material is called Biskin.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	16.20	9.00	37.66
0	32	42.19	23.44	98.07
25	77	83.20	46.22	193.38
50	122	116.15	64.53	269.99
55	131	120.42	66.90	279.91

heat of fusion: results is a mean value for temperature range -50° to 55°C (-58° to 131°F).

$L_f = 45.4\ \text{Btu lb}^{-1}$
$L_f = 25.2\ \text{cal g}^{-1}$
$L_f = 105.4\ \text{J g}^{-1}$

55RIE

PEANUTS; *Arachis hypogaea*; solid; 4.88% moisture.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 5472 Btu lb^{-1}
q_v(gross) = 3040 cal g^{-1}
q_v(gross) = 12720 J g^{-1}

55MER/WAT

PEARS, BARTLETT; solid; chemical analysis: 79.4% water, 0.51% fat, and 12.1% water soluble solids. Sample was unpeeled, cored, and cubed.

specific heat: 4° to -40°C (40° to -40°F); no freezing point was recorded.

temperature (°C)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} °C^{-1})	C_p(J g^{-1} °C^{-1})
4.44	40	0.98	0.98	4.10
- 6.67	20	3.24	3.24	13.56
-12.2	10	1.20	1.20	5.02
-17.0	0	0.83	0.83	3.47
-23.3	-10	0.63	0.63	2.64
-28.9	-20	0.51	0.51	2.13
-34.4	-30	0.46	0.46	1.93
-40	-40	0.44	0.44	1.84

49STA

PECANS; *Carya illinoensis*; solid; 4.30% moisture.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 6392 Btu lb^{-1}
q_v(gross) = 3551 cal g^{-1}
q_v(gross) = 14857 J g^{-1}

55MER/WAT

POTATO, WHITE; solid; proximate analysis: moisture, 79.5%; carbohydrates, 16.7%; protein, 2%; fiber, 0.4%; ash, 0.8%; fat, 0.1%.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 1526 \text{ Btu lb}^{-1}$
$q_V(\text{gross}) = 848 \text{ cal g}^{-1}$
$q_V(\text{gross}) = 3548 \text{ J g}^{-1}$

specific heat: at 303 K (86°F), with a moisture content (W) range of 0.23 to 0.83 wt. fraction.

(W > 0.50)		(0.50 > W > 0.20)	
$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1})$	$= 0.216 + 0.780\ W$	$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1})$	$\square\ 0.393 + 0.437\ W$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1})$	$= 0.216 + 0.780\ W$	$C_p(\text{cal g}^{-1}\ \text{K}^{-1})$	$= 0.393 + 0.437\ W$
$C_p(\text{J g}^{-1}\ \text{K}^{-1})$	$= 0.904 + 3.264\ W$	$C_p(\text{J g}^{-1}\ \text{K}^{-1})$	$= 1.644 + 1.828\ W$

55MER/WAT; 70YAM

RICE; *Oryza sativa*; solid; white; polished; 12.9% moisture.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 6937 \text{ Btu lb}^{-1}$
$q_V(\text{gross}) = 3854 \text{ cal g}^{-1}$
$q_V(\text{gross}) = 16125 \text{ J g}^{-1}$

55MER/WAT

RICE, FULLY FINISHED (ITALIAN ORIGIN); solid; Grain has fat content of 0.4%-2.0%. The relationship between the grain and the moisture content was determined. One third of the samples were not conditioned, one third were conditioned by adding distilled water and equilibrating for one week, and the rest were dried in a vacuum over $CaCl_2$ until they reached their respective moisture contents. Moisture content was determined by drying triplicate ground samples in a ventilated oven at 113°C (235°F) for 4 hours.

specific heat: straight line regression equations for the relation between the specific heat and moisture content where C_p is apparent specific heat and M is moisture content (%). The apparent specific heat of water [$C_p(w)$] was calculated from the equation for M $\square$ 100%.

$C_p \ \square\ 0.009\ M + 0.282 \text{ Btu lb}^{-1}\ {}^\circ\text{F}^{-1}$
$C_p = 0.009\ M + 0.282 \text{ cal g}^{-1}\ \text{K}^{-1}$
$C_p \ \square\ 0.038\ M + 1.180 \text{ J g}^{-1}\ \text{K}^{-1}$

$C_p(w) \ \square\ 1.182 \text{ Btu lb}^{-1}\ {}^\circ\text{F}^{-1}$
$C_p(w) = 1.182 \text{ cal g}^{-1}\ \text{K}^{-1}$
$C_p(w) = 4.946 \text{ J g}^{-1}\ \text{K}^{-1}$

54HAS

RICE, ROUGH (ITALIAN ORIGIN); solid; Grain has fat content of 0.4%-2.0%. The relationship between the grain and the moisture content was determined. One third of the samples were not conditioned, one third were conditioned by adding distilled water and equilibrating for one week, and the rest were dried in a vacuum over $CaCl_2$ until they reached their respective moisture contents. Moisture content was determined by drying triplicate ground samples in a ventilated oven at 113°C (235°F) for 4 hours.

specific heat: straight line regression equations for the relation between the specific heat and moisture content where C_p is apparent specific heat and M is moisture content (%). The apparent specific heat of water [$C_p(w)$] was calculated from the equation.

$C_p = 0.0107\ M + 0.265$ Btu $lb^{-1}\ °F^{-1}$
$C_p = 0.0107\ M + 0.265$ cal $g^{-1}\ K^{-1}$
$C_p = 0.0448\ M + 1.109$ J $g^{-1}\ K^{-1}$

$C_p(w) = 1.335$ Btu $lb^{-1}\ °F^{-1}$
$C_p(w) = 1.335$ cal $g^{-1}\ K^{-1}$
$C_p(w) = 5.586$ J $g^{-1}\ K^{-1}$

54HAS

RICE, SHELLED (ITALIAN ORIGIN); solid; Grain has fat content of 0.4%-2%. The relationship between the grain and the moisture content was determined. One third of the samples were not conditioned, oen third were conditioned by adding distilled water and equilibrating for one week, and the rest were dried in a vacuum over $CaCl_2$ until they reached their respective moisture contents. Moisture content was determined by drying triplicate ground samples in a ventilated oven at 113°C (235°F) for 4 hours.

specific heat: straight line regression equations for the relation between the specific heat and moisture content where C_p is apparent specific heat and M is moisture content (%). The apparent specific heat of water [$C_p(w)$] was calculated from the equation.

$C_p = 0.0091\ M + 0.287$ Btu $lb^{-1}\ °F^{-1}$
$C_p = 0.0091\ M + 0.287$ cal $g^{-1}\ K^{-1}$
$C_p = 0.0381\ M + 1.201$ J $g^{-1}\ K^{-1}$

$C_p(w) = 1.197$ Btu $lb^{-1}\ °F^{-1}$
$C_p(w) = 1.197$ cal $g^{-1}\ K^{-1}$
$C_p(w) = 5.008$ J $g^{-1}\ K^{-1}$

54HAS

RICE, SWAMP PADDY; solid; Grain was heavily husked rough rice from the Gold Coast area. Sample A was as harvested from field (germination was 41%); sample B was wetted by addition of water or water vapor, and sample C was dried in vacuum at 30°C (86°F) (germination was 39%).

specific heat: temperature range 273-291 K (32°-64°F); data are mean values with standard error in parentheses and moisture content (M) on a wet weight basis (%).

Sample	M %	C_p (Btu lb^{-1} °F^{-1})	C_p (cal g^{-1} K^{-1})	C_p (J g^{-1} K^{-1})
A	11.5	0.377(0.0032)	0.377(0.0032)	1.577(0.0134)
B	14.9	0.417(0.0037)	0.417(0.0037)	1.745(0.0155)
C	9.2	0.358(0.0040)	0.358(0.0040)	1.498(0.0167)

54DIS

WALNUTS, ENGLISH; *Juglans regia*; solid; 3.97% moisture.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 5972 Btu lb^{-1}
q_v(gross) = 3318 cal g^{-1}
q_v(gross) = 13882 J g^{-1}

55MER/WAT

WHALE OIL, HARDENED; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 193. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 72.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature (°C)	 (°F)	H°(t)-H°(-50°C) Btu lb^{-1}	 cal g^{-1}	 J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	16.02	8.90	37.24
0	32	38.11	21.17	88.58
25	77	71.14	39.52	165.35
50	122	117.43	65.24	272.96
55	131	121.79	67.66	283.09

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 48.6 Btu lb^{-1}
L_f = 27.9 cal g^{-1}
L_f = 113.0 J g^{-1}

55RIE

WHALE OIL, UNREFINED; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule ≈ 192. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 120.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	21.22	11.79	49.33
0	32	55.17	30.65	128.24
25	77	84.47	46.93	196.36
50	122	106.09	58.94	246.61
55	131	110.32	61.29	255.44

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 27.4 Btu lb^{-1}
L_f = 15.2 cal g^{-1}
L_f = 63.6 J g^{-1}

55RIE

WHEAT; *Triticum aestivum*; 8.5% moisture.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 7362 Btu lb^{-1}
q_v(gross) = 4090 cal g^{-1}
q_v(gross) = 17115 J g^{-1}

55MER/WAT

WHEAT, BERSEE; solid; Material is a soft white grain of French origin grown as a high-yielding winter or spring variety. Straight line regression equations for computing the specific heat (C_p) at different moisture contents (M) in percent are below. Moisture content was determined in a ventilated oven at 113°C (235°F) for 4 hours and calculated as a percentage of wet weight. Germination was either 100% or 0%.

specific heat: temperature range 273-291 K (32°-64°F). The apparent specific heat of water [$C_p(w)$] was computed from the regression equation by writing M = 100%.

M = 23.7%-33.6%

$C_p = 0.00731\ M + 0.336\ \text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}$
$C_p = 0.00731\ M + 0.336\ \text{cal g}^{-1}\ \text{K}^{-1}$
$C_p = 0.03059\ M + 1.406\ \text{J g}^{-1}\ \text{K}^{-1}$

$C_p(w) = 1.07\ \text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}$
$C_p(w) = 1.07\ \text{cal g}^{-1}\ \text{K}^{-1}$
$C_p(w) = 4.48\ \text{J g}^{-1}\ \text{K}^{-1}$

M = 7.7%-23.7%

$C_p = 0.01036\ M + 0.263\ \text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}$
$C_p = 0.01036\ M + 0.263\ \text{cal g}^{-1}\ \text{K}^{-1}$
$C_p = 0.04335\ M + 1.100\ \text{J g}^{-1}\ \text{K}^{-1}$

$C_p(w) = 1.30\ \text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}$
$C_p(w) = 1.30\ \text{cal g}^{-1}\ \text{K}^{-1}$
$C_p(w) = 5.44\ \text{J g}^{-1}\ \text{K}^{-1}$

M = 1.8%-7.7%

$C_p = 0.00591\ M + 0.297\ \text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}$
$C_p = 0.00591\ M + 0.297\ \text{cal g}^{-1}\ \text{K}^{-1}$
$C_p = 0.02473\ M + 1.243\ \text{J g}^{-1}\ \text{K}^{-1}$

$C_p(w) = 0.89\ \text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}$
$C_p(w) = 0.89\ \text{cal g}^{-1}\ \text{K}^{-1}$
$C_p(w) = 3.72\ \text{J g}^{-1}\ \text{K}^{-1}$

M = 0.0%-1.8%

$C_p = 0.00406\ M + 0.307\ \text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}$
$C_p = 0.00406\ M + 0.307\ \text{cal g}^{-1}\ \text{K}^{-1}$
$C_p = 0.01699\ M + 1.284\ \text{J g}^{-1}\ \text{K}^{-1}$

$C_p(w) = -0.10\ \text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}$
$C_p(w) = -0.10\ \text{cal g}^{-1}\ \text{K}^{-1}$
$C_p(w) = -0.42\ \text{J g}^{-1}\ \text{K}^{-1}$

54DIS

WHEAT, NO. 1 NORTHERN MANITOBA; solid; Grain had an initial moisture content of 13.7%. Samples of this batch were conditioned by drying in an oven (at either 60° or 113°C) or by addition of liquid water in air-tight jars. Material is a Canadian hard red spring wheat.

specific heat: temperature range 273-291 K (32°-64°F); data are mean values with standard error in parentheses and moisture content (M) is given in % on a wet weight basis.

M %	C_p ($\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}$)	C_p ($\text{cal g}^{-1}\ \text{K}^{-1}$)	C_p ($\text{J g}^{-1}\ \text{K}^{-1}$)
17.5	0.447(0.0027)	0.447(0.0027)	1.870(0.0113)
15.3	0.416(0.0021)	0.416(0.0021)	1.741(0.0088)
13.7	0.398(0.0020)	0.398(0.0020)	1.665(0.0084)
10.1	0.367(0.0039)	0.367(0.0039)	1.536(0.0163)
4.9	0.333(0.0024)	0.333(0.0024)	1.393(0.0100)
1.89	0.318(0.0024)	0.318(0.0024)	1.331(0.0100)
1.29	0.310(0.0029)	0.310(0.0029)	1.297(0.0121)

54DIS

Fossil Materials

ASPHALT; solid; mixture of paraffinic, aromatic, and heterocyclic hydrocarbons (containing oxygen, nitrogen, and sulfur).

specific heat: Venezuelan distilled asphalt.

Softening Point, °F	C_p(Btu lb^{-1} °F^{-1}) 32°F	212°F	392°F	572°F
103.1	0.425	0.472	0.520	0.567
144.5	0.409	0.463	0.518	0.572
205.7	0.382	0.455	0.527	0.600

Softening Point, °C	C_p(cal g^{-1} C^{-1}) 0°C	100°C	200°C	300°C
39.5	0.425	0.472	0.520	0.567
62.5	0.409	0.463	0.518	0.572
96.5	0.382	0.455	0.527	0.600

Softening Point, °C	C_p(J g^{-1} C^{-1}) 0°C	100°C	200°C	300°C
39.5	1.778	1.975	2.176	2.372
62.5	1.711	1.937	2.167	2.393
96.5	1.598	1.904	2.205	2.510

62BAR; 40SAA/HEU

COAL, ANTHRACITE; solid; ultimate analysis of combustible, ash free and moisture free: carbon, 94.39%; hydrogen, 1.77%; oxygen, 2.13%; nitrogen, 0.71%; sulfur, 1.00%; proximate analysis: ash, 7.83%; moisture, 2.80%; volatile matter, 1.3%; loss on air drying, 1.5%.

gross heat of combustion: assume values refer to room temperature.

ash free and moisture free	as received
q_v(gross) = 14890 Btu lb^{-1}	q_v(gross) = 13310 Btu lb^{-1}
q_v(gross) = 8273 cal g^{-1}	q_v(gross) = 7393 cal g^{-1}
q_v(gross) = 34616 J g^{-1}	q_v(gross) = 30931 J g^{-1}

18POO; 15LOR

COAL, BITUMINOUS; solid; National Bureau of Standards (NBS) Standard Reference Material (SRM) 1632a, Residual moisture, 1.145 wt. %; ash content, 22.15 wt. %; sulfur content, 1.48 wt. %.

gross heat of combustion: assume values refer to room temperature; values are on a moisture-free, ash-free basis.

q_V(gross) = 14534 Btu lb^{-1}
q_V(gross) = 8080 cal g^{-1}
q_V(gross) = 33806 J g^{-1}

81KIR/COL

COAL, BITUMINOUS (HIGH GRADE); solid; ultimate analysis of combustible, ash free and moisture free: carbon, 85.09%; hydrogen, 4.99%; oxygen, 6.99%; nitrogen, 1.80%; sulfur, 1.13%; proximate analysis: ash, 2.79%; moisture, 2.18%; volatile matter, 33.4%; loss on air drying, 1.0%.

gross heat of combustion: assume values refer to room temperature.

ash free and moisture free	as received
q_V(gross) = 15600 Btu lb^{-1}	q_V(gross) = 14830 Btu lb^{-1}
q_V(gross) = 8667 cal g^{-1}	q_V(gross) = 8237 cal g^{-1}
q_V(gross) = 36262 J g^{-1}	q_V(gross) = 34462 J g^{-1}

18POO; 15LOR

COAL, BITUMINOUS (LOW GRADE); solid; ultimate analysis of combustible, ash free and moisture free: carbon, 76.11%; hydrogen, 4.03%; oxygen, 16.14%; nitrogen, 0.84%; sulfur, 2.88%; proximate analysis: ash, 26.88%; moisture, 10.88%; volatile matter, 32.6%; loss on air drying, 5.4%.

gross heat of combustion: assume values refer to room temperature.

ash free and moisture free	as received
q_V(gross) = 12450 Btu lb^{-1}	q_V(gross) = 7747 Btu lb^{-1}
q_V(gross) = 6915 cal g^{-1}	q_V(gross) = 4304 cal g^{-1}
q_V(gross) = 28931 J g^{-1}	q_V(gross) = 18008 J g^{-1}

18POO; 15LOR

COAL, BITUMINOUS (MEDIUM GRADE); solid; (sample 1) ultimate analysis of combustible, ash free and moisture free: carbon, 82.08%; hydrogen, 5.40%; oxygen, 5.98%; nitrogen, 1.32%; sulfur, 5.22%; proximate analysis: ash, 12.97%; moisture, 4.99%; volatile matter, 39.8%; loss on air drying, 1.3%; (sample 2) ultimate analysis of combustible, ash free and moisture free: carbon, 76.55%; hydrogen, 5.26%; oxygen, 11.83%; nitrogen, 1.40%; sulfur, 4.96%; proximate analysis: ash, 23.38%; moisture, 17.30%; volatile matter, 44.6%; loss on air drying, 15.2%.

gross heat of combustion: assume values refer to room temperature.

sample 1, ash free and moisture free

$q_V(\text{gross}) = 14930\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 8296\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 34709\ \text{J g}^{-1}$

sample 2, ash free and moisture free

$q_V(\text{gross}) = 13900\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 7723\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 32313\ \text{J g}^{-1}$

sample 1, as received

$q_V(\text{gross}) = 12250\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 6806\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 28475\ \text{J g}^{-1}$

sample 2, as received

$q_V(\text{gross}) = 8246\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 4581\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 19166\ \text{J g}^{-1}$

18POO; 15LOR

COAL, CANNEL; solid; ultimate analysis of combustible, ash free and moisture free: carbon, 82.59%; hydrogen, 7.13%; oxygen, 7.57%; nitrogen, 1.33%; sulfur, 1.38%; proximate analysis: ash, 10.49%; moisture, 2.36%; volatile matter, 55.5%; loss on air drying, 1.5%.

gross heat of combustion: assume values refer to room temperature.

ash free and moisture free

$q_V(\text{gross}) = 15810\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 8784\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 36751\ \text{J g}^{-1}$

as received

$q_V(\text{gross}) = 13780\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 7655\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 32029\ \text{J g}^{-1}$

18POO; 15LOR

COAL, SEMI-ANTHRACITE; solid; ultimate analysis of combustible, ash free and moisture free: carbon, 92.15%; hydrogen, 3.76%; oxygen, 2.17%; nitrogen, 1.18%; sulfur, 0.74%; proximate analysis: ash, 11.50%; moisture, 3.38%; volatile matter, 10.0%; loss on air drying, 2.6%.

gross heat of combustion: assume values refer to room temperature.

ash free and moisture free

$q_V(\text{gross}) = 15470\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 8593\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 35953\ \text{J g}^{-1}$

as received

$q_V(\text{gross}) = 13170\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 7314\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 30601\ \text{J g}^{-1}$

18POO; 15LOR

COAL, SEMI-BITUMINOUS; solid; ultimate analysis of combustible, ash free and moisture free: carbon, 89.79%; hydrogen, 4.76%; oxygen, 2.47%; nitrogen, 2.00%; sulfur, 0.98%; proximate analysis: ash, 6.80%; moisture, 2.60%; volatile matter, 17.5%; loss on air drying, 2.0%.

gross heat of combustion: assume values refer to room temperature.

ash free and moisture free	as received
q_V(gross) = 15860 Btu lb^{-1}	q_V(gross) = 14370 Btu lb^{-1}
q_V(gross) = 8811 cal g^{-1}	q_V(gross) = 7983 cal g^{-1}
q_V(gross) = 36867 J g^{-1}	q_V(gross) = 33401 J g^{-1}

18POO; 15LOR

COAL, SUB-BITUMINOUS; solid; ultimate analysis of combustible, ash free and moisture free: carbon, 69.17%; hydrogen, 4.46%; oxygen, 24.35%; nitrogen, 1.66%; sulfur, 0.36%; proximate analysis: ash, 3.71%; moisture, 18.41%; volatile matter, 44.3%; loss on air drying, 10.0%.

gross heat of combustion: assume values refer to room temperature.

ash free and moisture free	as received
q_V(gross) = 11729 Btu lb^{-1}	q_V(gross) = 9137 Btu lb^{-1}
q_V(gross) = 6516 cal g^{-1}	q_V(gross) = 5076 cal g^{-1}
q_V(gross) = 27265 J g^{-1}	q_V(gross) = 21236 J g^{-1}

18POO; 15LOR

COKE; solid; produced from the destructive distillation of gas-coal in gas retorts; (sample 1, as received): fixed carbon, 59.56%; sulfur, 0.31%; moisture, 22.30%; ash, 17.56%; volatile matter, 0.58%; (sample 1, dry): fixed carbon, 76.65%; sulfur, 0.40%; ash, 22.60%; volatile matter, 0.75%; (sample 2, as received): fixed carbon, 67.89%; sulfur, 0.51%; ash, 4.45%; moisture, 26.80%; volatile matter, 0.86%; (sample 2, dry): fixed carbon, 92.75%; sulfur, 0.70%; ash, 6.08%; volatile matter, 1.17%; (dry represents sample as drawn from retort before quenching).

gross heat of combustion: assume values refer to room temperature.

sample 1, as received	sample 2, as received
q_V(gross) = 8687 Btu lb^{-1}	q_V(gross) = 10100 Btu lb^{-1}
q_V(gross) = 4826 cal g^{-1}	q_V(gross) = 5612 cal g^{-1}
q_V(gross) = 20192 J g^{-1}	q_V(gross) = 23479 J g^{-1}
sample 1, dry	**sample 2, dry**
q_V(gross) = 11180 Btu lb^{-1}	q_V(gross) = 13800 Btu lb^{-1}
q_V(gross) = 6211 cal g^{-1}	q_V(gross) = 7666 cal g^{-1}
q_V(gross) = 25988 J g^{-1}	q_V(gross) = 32076 J g^{-1}

18POO; 11WHI/BAR

COKE; solid; produced from the destructive distillation of bituminous coal in beehive ovens; (sample 1): fixed carbon, 91.43%; volatile carbon, 1.27%; sulfur, 0.51%; ash, 6.09%; (sample 2): fixed carbon, 79.83%; volatile carbon, 1.05%; sulfur, 2.13%; ash, 15.75%; water, 1.22%.

gross heat of combustion: assume values refer to room temperatures; corrected for moisture and ash content.

sample 1	sample 2
$q_V(\text{gross}) = 14420$ Btu lb^{-1}	$q_V(\text{gross}) = 13890$ Btu lb^{-1}
$q_V(\text{gross}) = 8011$ cal g^{-1}	$q_V(\text{gross}) = 7718$ cal g^{-1}
$q_V(\text{gross}) = 33520$ J g^{-1}	$q_V(\text{gross}) = 32292$ J g^{-1}

18POO

COKE; solid; produced from the destructive distillation to red heat of petroleum; fixed carbon, 98.05%; volatile carbon, 0.50%.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 14510$ Btu lb^{-1}
$q_V(\text{gross}) = 8063$ cal g^{-1}
$q_V(\text{gross}) = 33734$ J g^{-1}

18POO

COKE BREEZE; solid; ultimate analysis: carbon, 94.79%; hydrogen, 1.51%; oxygen, 1.48%; nitrogen, 1.19%; sulfur, 1.03%; proximate analysis: ash, 12.05%; moisture, 10.77%; volatile matter, 4.92%; loss on air drying, 10.1%.

gross heat of combustion: assume values refer to room temperature.

ash free and moisture free	as received
$q_V(\text{gross}) = 14470$ Btu lb^{-1}	$q_V(\text{gross}) = 11170$ Btu lb^{-1}
$q_V(\text{gross}) = 8038$ cal g^{-1}	$q_V(\text{gross}) = 6204$ cal g^{-1}
$q_V(\text{gross}) = 33632$ J g^{-1}	$q_V(\text{gross}) = 25958$ J g^{-1}

18POO; 15FER

FUEL, AVIATION; liquid; petroleum fraction with B.P. range 175°-350°C (347°-662°F) (kerosine). Military jet fuels labeled JP-3, JP-4, JP-5, etc. Commercial jet fuels labeled as ASTM types A, A-1, or B.

net heat of combustion: A is the aniline point, in degrees Fahrenheit, identifying the minimum equilibrium solution temperature for equal volumes of aniline and sample. G is the API gravity defined as: API gravity (deg) = 141.5/(sp. gr. 60/60°F)-131.5. Tables are provided in ASTM Specification D 1405 to calculate q_p (net) if sulfur impurities are known.

Aviation gasoline, Grades 100-130 and 115-145:

$q_p(\text{net}) = [18049 + 0.0833\,(A \times G)]\ \text{Btu lb}^{-1}$
$q_p(\text{net}) = [10027 + 0.0463\,(A \times G)]\ \text{cal g}^{-1}$
$q_p(\text{net}) = [41954 + 0.1938\,(A \times G)]\ \text{J g}^{-1}$

Jet fuels:

JP-3

$q_p(\text{net}) = [17951 + 0.1057\,(A \times G)]\ \text{Btu lb}^{-1}$
$q_p(\text{net}) = [9973 + 0.0587\,(A \times G)]\ \text{cal g}^{-1}$
$q_p(\text{net}) = [41728 + 0.2456\,(A \times G)]\ \text{J g}^{-1}$

JP-4

$q_p(\text{net}) = [17989 + 0.1057\,(A \times G)]\ \text{Btu lb}^{-1}$
$q_p(\text{net}) = [9994 + 0.0587\,(A \times G)]\ \text{cal g}^{-1}$
$q_p(\text{net}) = [41815 + 0.2456\,(A \times G)]\ \text{J g}^{-1}$

JP-5

$q_p(\text{net}) = [17926 + 0.1057\,(A \times G)]\ \text{Btu lb}^{-1}$
$q_p(\text{net}) = [9959 + 0.0587\,(A \times G)]\ \text{cal g}^{-1}$
$q_p(\text{net}) = [41668 + 0.2456\,(A \times G)]\ \text{J g}^{-1}$

Kerosine, Jet A or A-1 (see ASTM Speciation D 1655):

$q_p(\text{net}) = [17932 + 0.10930\,(A \times G)]\ \text{Btu lb}^{-1}$
$q_p(\text{net}) = [9962 + 0.06072\,(A \times G)]\ \text{cal g}^{-1}$
$q_p(\text{net}) = [41680 + 0.25407\,(A \times G)]\ \text{J g}^{-1}$

68AST

FUEL, AVIATION; liquid; petroleum fraction with B.P. range 175°-350°C (347°-662°F).

gross heat of combustion: assume values refer to 25°C (77°F).

aviation gasoline, grade 91-96:

q_v(gross) = 20232 Btu lb^{-1}
q_v(gross) = 11240 cal g^{-1}
q_v(gross) = 47028 J g^{-1}

aviation gasoline, grade 100-130:

q_v(gross) = 20288 Btu lb^{-1}
q_v(gross) = 11271 cal g^{-1}
q_v(gross) = 47158 J g^{-1}

48LET/MAT

FUEL, COED-1 FMC WESTERN KENTUCKY COAL DERIVED; liquid; Material was refined by fractionation. Composition was nitrogen = 40 ppm, sulfur = 0.05 wt. %, aromatics = 24.8%, C_9 to C_{16} n-alkanes = 3.90 wt. %, and hydrogen = 12.80 wt. %. The freezing point is -48°C (-54°F).

net heat of combustion: assume values refer to room temperature; where net heat of combustion [q (net at 25°C)] = gross heat of combustion [q (gross at 25°C)] - 91.23 H, where H = hydrogen weight % of the sample.

q_v(net) = 18294 Btu lb^{-1}
q_v(net) = 10163 cal g^{-1}
q_v(net) = 42523 J g^{-1}

76HAZ/HAL

FUEL, COED-2 UTAH COAL DERIVED; liquid; Material was refined by fractionation. Composition was nitrogen = 42 ppm, sulfur = 0.04 wt. %, aromatics = 24.1%, C_9 to C_{16} n-alkanes = 7.14 wt. %, and hydrogen = 12.98 wt. %. The freezing point is -40°C (-40°F).

net heat of combustion: assume values refer to room temperature; where net heat of combustion [q (net at 25°C)] = gross heat of combustion [q (gross at 25°C)] - 91.23 H, where H = hydrogen weight % of the sample.

q_v(net) = 18327 Btu lb^{-1}
q_v(net) = 10207 cal g^{-1}
q_v(net) = 42705 J g^{-1}

76HAZ/HAL

FUEL, COED-3 WESTERN KENTUCKY COAL DERIVED; liquid; Material was refined by fractionation. Composition was nitrogen = 40 ppm, sulfur = 0.05 wt. %, aromatics = 4.7%, C_9 to C_{16} n-alkanes = 3.73 wt. %, and hydrogen = 13.34 wt. %. The freezing point is -50°C (-58°F).

net heat of combustion: assume values refer to room temperature; where net heat of combustion [q (net at 25°C)] = gross heat of combustion [q (gross at 25°C)] - 91.23 H, where H = hydrogen weight % of the sample.

q_v(net) = 18383 Btu lb^{-1}
q_v(net) = 10213 cal g^{-1}
q_v(net) = 42730 J g^{-1}

76HAZ/HAL

FUEL, COED-4 UTAH COAL DERIVED; liquid; Material was refined by fractionation. Composition was nitrogen = 43 ppm, sulfur = 0.03 wt. %, aromatics = 6.1%, C_9 to C_{16} n-alkanes = 7.45 wt. %, and hydrogen = 13.62 wt. %. The freezing point is -40°C (-40°F).

net heat of combustion: assume values refer to room temperature; where net heat of combustion [q (net at 25°C)] = gross heat of combustion [q (gross at 25°C)] - 91.23 H, where H = hydrogen weight % of the sample.

q_v(net) = 18465 Btu lb^{-1}
q_v(net) = 10258 cal g^{-1}
q_v(net) = 42921 J g^{-1}

76HAZ/HAL

FUEL, COED-5 WESTERN KENTUCKY COAL DERIVED; liquid; Material was refined by fractionation. Composition was nitrogen = 37 ppm, sulfur = 0.03 wt. %, aromatics = 24.1%, C_9 to C_{16} n-alkanes = 5.48 wt. %, and hydrogen = 12.81 wt. %. The freezing point is -56.7°C (-70°F).

net heat of combustion: assume values refer to room temperature; where net heat of combustion [q (net at 25°C)] = gross heat of combustion [q (gross at 25°C)] - 91.23 H, where H = hydrogen weight % of the sample.

q_v(net) = 18282 Btu lb^{-1}
q_v(net) = 10157 cal g^{-1}
q_v(net) = 42495 J g^{-1}

76HAZ/HAL

FUEL, JP-9 RAMJET; liquid; Material is a blend of 10.3 wt. % methylcyclohexane, 68.4 wt. % of exo-tetrahydrodicyclopentadiene, and 21.2 wt. % of the hydrogenated dimers of norbornadiene whose empirical formula is $C_{14}H_{18}$; the empirical formula for the blend is $C_{10.529}H_{16.202}$. Recovery of CO_2 from the combustion products gave a mean value of 99.63_0%.

gross heat of combustion: The reference temperature is 298.15 K (77°F). Value is mean with standard deviation of the mean.

q_v(gross) = 19204.49 ± 1.40 Btu lb^{-1}
q_v(gross) = 10669.16 ± 0.78 cal g^{-1}
q_v(gross) = 44639.77 ± 3.26 J g^{-1}

net heat of combustion: The reference temperature is 298.15 K (77°F). Value is mean with standard deviation of the mean.

q_v(net) = 18160.7 ± 4.3 Btu lb^{-1}
q_v(net) = 10089.3 ± 2.4 cal g^{-1}
q_v(net) = 42213.6 ± 10. J g^{-1}

78SMI/GOO

FUEL, PARAHO OIL SHALE DERIVED; liquid; Material was refined by delayed coking and fractionation. Composition was nitrogen = 680 ppm, sulfur = 0.05 wt. %, aromatics = 26.0%, C_9 to C_{16} n-alkanes = 36.33 wt. %, and hydrogen = 13.74 wt. %. The freezing point is -33.3°C (-28°F).

net heat of combustion: assume values refer to room temperature, where net heat of combustion [q (net at 25°C)] = gross heat of combustion [q (gross at 25°C)] - 91.23 H where H = hydrogen weight % of sample.

q_v(net) = 18532 Btu lb^{-1}
q_v(net) = 10296 cal g^{-1}
q_v(net) = 43077 J g^{-1}

76HAZ/HAL

FUEL, PETROLEUM-A DERIVED; liquid; Material was produced by drilling. Composition was sulfur = 0.11 wt. %, aromatics = 18.2%, C_9 to C_{16} n-alkanes = 16.00 wt. %. The freezing point is -48.9°C (-56°F).

net heat of combustion: assume values refer to room temperature.

q_v(net) = 18518 Btu lb^{-1}
q_v(net) = 10288 cal g^{-1}
q_v(net) = 43044 J g^{-1}

76HAZ/HAL

FUEL, RJ-4 RAMJET; liquid; Material, exo-tetrahydrodi (methylcyclopentadiene) is a mixture of isomers in which the location of the methyl groups is unknown. Recovery of CO_2 from combustion products gave a mean value of 99.98_3%.

gross heat of combustion: The reference temperature is 298.15 K (77°F). Value is mean value with standard deviation of the mean.

$q_V(\text{gross}) = 19396.22 \pm 1.44$ Btu lb^{-1}
$q_V(\text{gross}) = 10775.68 \pm 0.80$ cal g^{-1}
$q_V(\text{gross}) = 45085.45 \pm 3.35$ J g^{-1}

net heat of combustion: The reference temperature is 298.15 K (77°F). Value is mean value with standard deviation of the mean.

$q_V(\text{net}) = 18275.6 \pm 4.1$ Btu lb^{-1}
$q_V(\text{net}) = 10153.1 \pm 2.3$ cal g^{-1}
$q_V(\text{net}) = 42480.6 \pm 9.6$ J g^{-1}

78SMI/GOO

FUEL, RJ-4 RAMJET; liquid; Material is a complex mixture of isomers, all of formula $C_{12}H_{20}$. Carbon dioxide recovery from combustion products was $99.98_3 \pm 0.00_6$% of that expected.

gross heat of combustion: temperature, 298.15 K (77°F).

$q_V(\text{gross}) = 19427.95 \pm 4.16$ Btu lb^{-1}
$q_V(\text{gross}) = 10793.31 \pm 2.31$ cal g^{-1}
$q_V(\text{gross}) = 45159.20 \pm 9.68$ J g^{-1}

net heat of combustion: temperature, 298.15 K (77°F).

$q_V(\text{net}) = 18275.39 \pm 4.16$ Btu lb^{-1}
$q_V(\text{net}) = 10152.99 \pm 2.31$ cal g^{-1}
$q_V(\text{net}) = 42480.13 \pm 9.68$ J g^{-1}

77GOO/SCO

FUEL, RJ-4-I RAMJET; liquid; Material, endo-tetrahydrodi (methylcyclopentadiene), is a mixture of isomers in which the location of the methyl groups is unknown. Recovery of CO_2 from combustion products gave a mean value of 99.96_2%.

gross heat of combustion: The reference temperature is 298.15 K (77°F). Value is mean with standard deviation of the mean.

$q_V(\text{gross}) = 19374.55 \pm 1.03$ Btu lb^{-1}
$q_V(\text{gross}) = 10763.64 \pm 0.57$ cal g^{-1}
$q_V(\text{gross}) = 45035.07 \pm 2.38$ J g^{-1}

(more)

FUEL, RJ-4-I RAMJET - Continued

net heat of combustion: The reference temperature is 298.15 K (77°F). Value is mean with standard deviation of mean.

$q_v(\text{net}) = 18254.5 \pm 4.0$ Btu lb^{-1}
$q_v(\text{net}) = 10141.4 \pm 2.2$ cal g^{-1}
$q_v(\text{net}) = 42431.6 \pm 9.2$ J g^{-1}

78SMI/GOO

FUEL, RJ-6 RAMJET; liquid; Material is a blend of exo-tetrahydrodicyclopentadiene and the hydrogenated dimers of norbornadiene and used without further drying. The ratio of CO_2 recovered to mass of sample burned was 3.2725 ± 0.0002 (mean and standard deviation of the mean). The empirical formula calculated from this ratio is $CH_{1.4259}$.

gross heat of combustion: temperature, 298.15 K (77°F).

$q_v(\text{gross}) = 18959.58 \pm 0.43$ Btu lb^{-1}
$q_v(\text{gross}) = 10533.10 \pm 0.24$ cal g^{-1}
$q_v(\text{gross}) = 44070.49 \pm 1.00$ J g^{-1}

net heat of combustion: temperature, 298.15 K (77°F).

$q_v(\text{net}) = 17971.8 \pm 0.4$ Btu lb^{-1}
$q_v(\text{net}) = 9983.9 \pm 0.2$ cal g^{-1}
$q_v(\text{net}) = 41774.5 \pm 0.9$ J g^{-1}

heat capacity: temperature range 260-340 K (9°-153°F), and C_s is the heat capacity of the substance in equilibrium with its saturated vapor. The root mean square deviation of results was 0.0055 cal g^{-1} K^{-1}.

$C_s(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.31378 + 4.97 \times 10^{-4}\ T$
$C_s(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.0852880 + 8.948 \times 10^{-4}\ T$
$C_s(\text{J g}^{-1}\ \text{K}^{-1}) = 0.3568450 + 3.7438 \times 10^{-3}\ T$

79SMI/SCO

FUEL, RJ-6 RAMJET; liquid; Material is a blend of JP-10 (exo-tetrahydrodicyclopentadiene) and 3 hydrogenated dimers of norbornadienes.

heat capacity: Temperature range was 260-467 K (9°-381°F), and uncertainties are standard deviations at either end of the measurement range. The 1961 atomic weights and thermochemical calorie were used.

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.2939 + 6.0905 \times 10^{-4}\ T) \pm 0.00056$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = (0.013913 + 0.10963 \times 10^{-2}\ T) \pm 0.00056$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = (0.058212 + 0.45869 \times 10^{-2}\ T) \pm 0.00234$

80SMI/THO

FUEL, TAR SANDS (ALTERNATIVE JET FUEL); liquid; Canadian sample was refined by delayed coking and fractionation. Partial composition was sulfur = 0.01 wt. %, aromatics = 19.3%, C_9 to C_{16} n-alkanes = 9.50 wt. %, and hydrogen = 13.50 wt. %. The freezing point is -53.3°C (-64°F).

net heat of combustion: assume values refer to room temperature; where net heat of combustion [q (net at 25°C)] = gross heat of combustion [q (gross at 25°C)] - 91.23 H, where H = hydrogen weight % of the sample.

q_v(net) = 18436 Btu lb^{-1}
q_v(net) = 10242 cal g^{-1}
q_v(net) = 42853 J g^{-1}

76HAZ/HAL

GAS, NATURAL; gas; composition in mole percent; (sample A), N_2 = 15.6%, He = 0.84%, CO_2 = 0.03%, CH_4 = 72.2%, C_2H_6 = 6.5%, propane = 3.8%, n-butane = 0.66%, isobutane = 0.28%, pentanes = 0.02%, hexanes = 0.01%, and heptanes = 0.01%. (sample B), N_2 = 2.8%, He = 0.23%, CO_2 = 0.19%, CH_4 = 86.2%, C_2H_6 = 6.2%, propane = 2.7%, n-butane = 0.63%, isobutane = 0.52%, pentanes = 0.32%, hexanes = 0.22%, and heptanes = 0.07%. (sample C), N_2 = 0.24%, He = 0.00%, CO_2 = 0.87%, CH_4 = 94.7%, C_2H_6 = 3.2%, propane = 0.67%, n-butane = 0.12%, isobutane = 0.06%, pentanes = 0.06%, hexanes = 0.06%, and heptanes = 0.04%. (sample D), N_2 = 7.1%, He = 0.32%, CO_2 = 0.49%, CH_4 = 84.3%, C_2H_6 = 5.2%, propane = 1.9%, n-butane = 0.31%, isobutane = 0.28%, pentanes = 0.04%, hexanes = 0.04%, and heptanes = 0.03%.

gross heat of combustion: at 15.56°C (60°F) and 101325 Pa (1 atm); where SCF is standard cubic foot.

sample A

q_v(gross) = 958 Btu(SCF)$^{-1}$
q_v(gross) = 8.51×10^6 cal m^{-3}
q_v(gross) = 35.7×10^6 J m^{-3}

sample B

q_v(gross) = 1101 Btu(SCF)$^{-1}$
q_v(gross) = 9.80×10^6 cal m^{-3}
q_v(gross) = 41.0×10^6 J m^{-3}

sample C

q_v(gross) = 1028 Btu(SCF)$^{-1}$
q_v(gross) = 9.15×10^6 cal m^{-3}
q_v(gross) = 38.3×10^6 J m^{-3}

sample D

q_v(gross) = 999 Btu(SCF)$^{-1}$
q_v(gross) = 8.89×10^6 cal m^{-3}
q_v(gross) = 37.2×10^6 J m^{-3}

compressibility factor, Z = PV/RT: at 15.56°C (60°F) and 101325 Pa (1 atm).

Z (sample A) = 0.9978
Z (sample B) = 0.9974
Z (sample C) = 0.9978
Z (sample D) = 0.9979

61MAS/EAK

GASOLINE; liquid; a mixture of volatile hydrocarbons with boiling points ranging from 60°-198°C (140°-390°F) (branched-chain paraffins, cycloparaffins, and aromatics).

auto-ignition temperature:

octane rating	temperature °C	temperature °F
65	248	478
73	258	496
87	412	774

54SET

GASOLINE; liquid; a mixture of volatile hydrocarbons with boiling points ranging from 140°-390°F (branched-chain paraffins, cycloparaffins, and aromatics).

gross heat of combustion: assume values refer to room temperature.

Production motor gasoline:

regular grade	premium grade
$q_v(\text{gross}) = 19990 \text{ Btu lb}^{-1}$	$q_v(\text{gross}) = 20079 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 11106 \text{ cal g}^{-1}$	$q_v(\text{gross}) = 11155 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 46466 \text{ J g}^{-1}$	$q_v(\text{gross}) = 46673 \text{ J g}^{-1}$

48LET/MAT

GREASE, APIEZON N; solid; low vapor-pressure residues of paraffin oil distillation products.

specific heat:

In the temperature range: -193° to -73°C (-315° to -99°F).

$$C_p(\text{Btu lb}^{-1}\,{}^\circ\text{F}^{-1}) = -3.0315 \times 10^{-3} + 1.1378 \times 10^{-3}(t + 459.67) - 1.8554 \times 10^{-6}(t + 459.67)^2 + 2.4581 \times 10^{-9}(t + 459.67)^3$$

$$C_p(\text{cal g}^{-1}\,{}^\circ\text{C}^{-1}) = -3.0315 \times 10^{-3} + 2.0481 \times 10^{-3}(t + 459.67) - 6.0115 \times 10^{-6}(t + 459.67)^2 + 1.4336 \times 10^{-8}(t + 459.67)^3$$

$$C_p(\text{J g}^{-1}\,{}^\circ\text{C}^{-1}) = -1.2684 \times 10^{-2} + 4.7606 \times 10^{-3}(t + 459.67) - 2.5152 \times 10^{-5}(t + 459.67)^2 + 5.9982 \times 10^{-8}(t + 459.67)^3$$

(more)

GREASE, APIEZON N - Continued

In the temperature range -73° to 57°C, (-99° to 124°F), C_p is anomalous; values are given below

temperature (°C)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} °C^{-1})	C_p(J g^{-1} °C^{-1})
-73	-99	0.281	0.281	1.18
-63	-81	0.301	0.301	1.26
-53	-63	0.344	0.344	1.44
-43	-45	0.392	0.392	1.64
-33	-27	0.421	0.421	1.76
-23	- 9	0.445	0.445	1.86
-13	9	0.468	0.468	1.96
- 3	27	0.543	0.543	2.27
7	45	0.679	0.679	2.84
17	63	0.853	0.853	3.57
23	73	0.899	0.899	3.76
27	81	0.858	0.858	3.59
37	99	0.626	0.626	2.62
47	117	0.554	0.554	2.32
57	135	0.538	0.538	2.25

69BUN/ASH

GREASE, APIEZON P; solid; low vapor-pressure residues of paraffin oil distillation products; average molecular weight 410 ± 70.

heat of vaporization: temperature range 40°-160°C (104°-320°F).

L_v = 152.5 Btu lb^{-1}
L_v = 84.70 cal g^{-1}
L_v = 354.4 J g^{-1}

vapor pressure: temperature range 40°-160°C (104°-320°F).

$\log_{10} P(\text{Torr}) = 13.91 - 7590\ T^{-1}$ (K)
$\log_{10} P(\text{Pa}) = 16.03 - 7590\ T^{-1}$ (K)

57HER/REI

GREASE, APIEZON R; solid; low vapor-pressure residues of paraffin oil distillation products; average molecular weight 660 ± 100.

heat of vaporization: temperature range 40°-160°C (104°-320°F).

$L_v = 87.98$ Btu lb^{-1}
$L_v = 48.88$ cal g^{-1}
$L_v = 204.5$ J g^{-1}

vapor pressure: temperature range 40°-160°C (104°-320°F).

$\log_{10} P(\text{Torr}) = 12.54 - 7050\ T^{-1}$ (K)
$\log_{10} P(\text{Pa}) = 14.66 - 7050\ T^{-1}$ (K)

57HER/REI

GREASE, APIEZON S; solid; low vapor-pressure residues of paraffin oil distillation products; average molecular weight 460 ± 60.

heat of vaporization: temperature range 40°-160°C (104°-320°F).

$L_v = 22.54$ Btu lb^{-1}
$L_v = 70.08$ cal g^{-1}
$L_v = 293.2$ J g^{-1}

vapor pressure: temperature range 40°-160°C (104°-320°F).

$\log_{10} P(\text{Torr}) = 12.52 - 7045\ T^{-1}$ (K)
$\log_{10} P(\text{Pa}) = 14.64 - 7045\ T^{-1}$ (K)

57HER/REI

GREASE, APIEZON T; solid; low vapor-pressure residues of paraffin oil distillation products; also contains an aluminum soap.

specific heat: specific heat is anomalous between 205 and 320 K.

temperature				
(K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
5	-450.4	0.001035	0.001035	0.0004330
50	-369.4	0.07746	0.07746	0.3241
100	-279.4	0.1518	0.1518	0.6351
150	-189.4	0.2149	0.2149	0.8991
200	- 99.4	0.2811	0.2811	1.1761
220	- 63.4	0.362	0.362	1.515
240	- 27.4	0.447	0.447	1.870
260	8.6	0.498	0.498	2.084
280	44.6	0.526	0.526	2.201
300	80.6	0.517	0.517	2.163
320	116.6	0.5022	0.5022	2.101
340	152.6	0.5180	0.5180	2.167
350	170.6	0.5259	0.5259	2.200

67WES/CHI

KEROSINE; liquid; mixture of hydrocarbons with boiling points ranging from 180°-300°C (356°-572°F); ultimate composition: carbon, 85.8%; hydrogen, 14.2%; sulfur, 58 ppm; total paraffins, 30.9%; total naphthenes, 64.3%; total aromatics, 4.8%; density, 0.8019 g cm^{-3} at 24°C (75°F); API gravity, 43.5.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 19957 Btu lb^{-1}
q_V(gross) = 11087 cal g^{-1}
q_V(gross) = 46390 J g^{-1}

73LEN/HIP

LIGNITE; solid; Lignite is also called Brown Coal. (sample 1) ultimate analysis: carbon, 68.32%; hydrogen, 4.00%; oxygen, 25.54%; nitrogen, 1.42%; sulfur, 0.72%; proximate analysis: ash, 13.27%; moisture, 23.30%; volatile matter, 43.5%; loss on air drying, 17.3%; (sample 2) ultimate analysis: carbon, 63.30%; hydrogen, 3.32%; oxygen, 29.86%; nitrogen, 1.35%; sulfur, 2.17%; proximate analysis: ash, 10.12%; moisture, 31.37%; volatile matter, 50.6%; loss on air drying, 14.2%.

gross heat of combustion: assume values refer to room temperature.

sample 1, ash free and moisture free

q_V(gross) = 11040 Btu lb^{-1}
q_V(gross) = 6132 cal g^{-1}
q_V(gross) = 25656 J g^{-1}

sample 1, as received

q_V(gross) = 8105 Btu lb^{-1}
q_V(gross) = 4503 cal g^{-1}
q_V(gross) = 18841 J g^{-1}

sample 2, ash free and moisture free

q_V(gross) = 9635 Btu lb^{-1}
q_V(gross) = 5353 cal g^{-1}
q_V(gross) = 22399 J g^{-1}

sample 2, as received

q_V(gross) = 5638 Btu lb^{-1}
q_V(gross) = 3132 cal g^{-1}
q_V(gross) = 13104 J g^{-1}

18POO; 15LOR

NAPHTHA, ALASKA; liquid; ultimate analysis: carbon, 86.3%; hydrogen, 13.7%; nitrogen, 0.3 ppm; sulfur, 99 ppm; total paraffins, 39.7%; total naphthenes, 39.6%; total aromatics, 20.5%; density, 0.7703 g cm^{-3} at 24°C (75°F); API gravity, 50.5.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 19514 Btu lb^{-1}
q_V(gross) = 10841 cal g^{-1}
q_V(gross) = 45360 J g^{-1}

73LEN/HIP

NAPHTHA, AROMATIC; liquid; ultimate analysis: carbon, 90.1%; hydrogen, 9.8%; sulfur, 760 ppm; total paraffins, 0.0%; total naphthenes, 0.0%; total aromatics, 83.1%; total olefins, 16.9%; density, 0.8449 g cm^{-3} at 24°C (75°F); API gravity, 34.5.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 18517 Btu lb^{-1}
q_v(gross) = 10287 cal g^{-1}
q_v(gross) = 43040 J g^{-1}

73LEN/HIP

NAPHTHA, HIGH BOILING; liquid; ultimate analysis: carbon, 85.4%; hydrogen, 14.6%; sulfur, 357 ppm; total paraffins, 59.3%; total naphthenes, 30.8%; total aromatics, 9.9%; density, 0.7559 g cm^{-3} at 24°C (75°F); API gravity, 54.2.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 20191 Btu lb^{-1}
q_v(gross) = 11217 cal g^{-1}
q_v(gross) = 46934 J g^{-1}

73LEN/HIP

NAPHTHA, JET; liquid; ultimate analysis: carbon, 86.05%; hydrogen, 13.95%; sulfur, 132 ppm; total paraffins, 18.6%; total naphthenes, 69.8%; total aromatics, 10.6%; sulfur compounds, 10,000 ppm density, 0.7981 g cm^{-3} at 24°C (75°F); API gravity, 44.4.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 19845 Btu lb^{-1}
q_v(gross) = 11025 cal g^{-1}
q_v(gross) = 46129 J g^{-1}

73LEN/HIP

NAPHTHA, LOW BOILING; liquid; ultimate analysis: carbon, 85.1%; hydrogen, 14.9%; sulfur, 376 ppm; total paraffins, 61.9%; total naphthenes, 30.6%; total aromatics, 7.6%; density, 0.7559 g cm^{-3} at 24°C (75°F); API gravity, 59.9.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 20277 Btu lb^{-1}
q_v(gross) = 11265 cal g^{-1}
q_v(gross) = 47132 J g^{-1}

73LEN/HIP

OIL, CRUDE; liquid; ADMEG, Zakum (export), specific gravity 60/60°F = 0.8256, upper pour point □ -15°C, wax content = 7.0 wt. %; Barrow Island, specific gravity 60/60°F = 0.8399, upper pour point < -50°C, wax content < 1 wt. %; Libyan (Tobruk export), specific gravity 60/60°F = 0.8429, upper pour point = 24°C, wax content = 20.0 wt. %; Iranian Light (export), specific gravity 60/60°F = 0.8568, upper pour point □ -21°C, wax content = 7.0 wt. %; Kuwait (export), specific gravity 60/60°F = 0.8709, upper pour point = -32°C, wax content = 5.5 wt. %; Iranian Heavy (export), specific gravity 60/60°F = 0.8732, upper pour point = -12°C, wax content = 6.7 wt. %; Alaskan (North Slope), specific gravity 60/60°F = 0.8914, upper pour point □ -1°C, wax content = 6.5 wt. %.

gross heat of combustion: assume values refer to room temperature.

$q_v(\text{gross}) = 22320 - 3780d^2$ Btu lb^{-1}
$q_v(\text{gross}) = 12400 - 2100d^2$ cal g^{-1}
$q_v(\text{gross}) = 51881.6 - 8786.4d^2$ J g^{-1}

where d is the specific gravity at 60/60°F, equation assumes crude oil to be water, ash, and sulfur free; combustion products are gaseous CO_2 and liquid H_2O.

$q_p'(\text{gross}) = 1.8\ q_v(\text{gross}) - 0.018\ q_v(\text{gross})X + 40.5\ (\%S)$ Btu lb^{-1}
$q_v'(\text{gross}) = q_v(\text{gross}) - 0.01\ q_v(\text{gross})X + 22.5\ (\%S)$ cal g^{-1}
$q_v'(\text{gross})$ □ $q_v(\text{gross}) - 0.04\ q_v(\text{gross})X + 94.1\ (\%S)$ J g^{-1}

where $q_v'(\text{gross})$ is heat of combustion at constant volume of crude oil yielding ash, gaseous CO_2, SO_2, and liquid H_2O as combustion products; $X = (\%H_2O + \%\text{ash} + \%S)$

specific heat: The equation provided is based on over 100 measurements made at the National Bureau of Standards over the temperature range 273-477 K (32°-400°F). The experimental results differ from the values calculated from this equation by less than 2%, with a maximum deviation of 4%; oils from mixed base crudes are in good agreement; oils from paraffin base crudes are systematically high by about 2%; oils from naphthene base crudes are systematically low by about 2%.

C_p(Btu lb^{-1} °F^{-1}) $= (0.3880 + 4.5 \times 10^{-4}\ T)/d^{\frac{1}{2}}$
C_p(cal g^{-1} K^{-1}) $= (0.1811 + 8.1 \times 10^{-4}\ T)/d^{\frac{1}{2}}$
C_p(J g^{-1} K^{-1}) $= (0.7577 + 3.39 \times 10^{-3}\ T)/d^{\frac{1}{2}}$

where d is the specific gravity at 60/60°F.

29CRA

OIL, FUEL; liquid; ultimate analysis: carbon, 86.9%; hydrogen, 13.1%; sulfur, 172 ppm; total paraffins, 29.8%; total naphthenes, 45.6%; total aromatics, 22.4%; sulfur compounds, 1.3%; density, 0.8553 g cm^{-3} at 24°C (75°F); API gravity 33.0.

gross heat of combustion: assume values refer to room temperature.

$q_v(\text{gross}) = 17570$ Btu lb^{-1}
$q_v(\text{gross}) = 9763$ cal g^{-1}
$q_v(\text{gross}) = 40847$ J g^{-1}

73LEN/HIP

OIL, GAS; liquid; ultimate analysis: carbon, 86.5%; hydrogen, 13.4%; sulfur, 261 ppm; nitrogen, 3 ppm; total paraffins, 38.8%; total naphthenes, 41.5%; total aromatics, 17.2%; sulfur compounds, 2.4%; density, 0.8415 g cm^{-3} at 24°C (75°F); API gravity, 35.3.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 19759 Btu lb^{-1}
q_V(gross) = 10977 cal g^{-1}
q_V(gross) = 45927 J g^{-1}

73LEN/HIP

OIL, PARAFFIN; liquid; repeating unit: $CH_{1.891}$.

gross heat of combustion: 25°C (77°F)

q_V(gross) = 19771 Btu lb^{-1}
q_V(gross) = 10984 cal g^{-1}
q_V(gross) = 45957 J g^{-1}

60GOO/LAC

OIL, PARAFFIN; liquid; low vapor-pressure residues of paraffin oil distillation products.

Apiezon C: average molecular weight 450 ± 70; temperature range 40°-160°C (104°-320°F).

heat of vaporization:

L_V = 108.45 Btu lb^{-1}
L_V = 60.25 cal g^{-1}
L_V = 252.1 J g^{-1}

vapor pressure:

$\log_{10} P(\text{Torr}) = 11.67 - 5925\ T^{-1}(\text{K})$
$\log_{10} P(\text{Pa}) = 13.79 - 5925\ T^{-1}(\text{K})$

Apiezon E: average molecular weight 290 ± 30; temperature range 40° 160°C (104°-320°F).

L_V = 144.85 Btu lb^{-1}
L_V = 80.47 cal g^{-1}
L_V = 336.7 J g^{-1}

vapor pressure:

$\log_{10} P(\text{Torr}) = 9.30 - 5100\ T^{-1}(\text{K})$
$\log_{10} P(\text{Pa}) = 11.42 - 5100\ T^{-1}(\text{K})$

57HER/REI

OIL, RAW SHALE; solid; Material came from the Anvil Points mine in Colorado and was riffled and split before retorting and combined with benzoic acid in a 1:1 ratio to achieve complete combustion in the bomb calorimeter. Combustion analysis indicated: H_2O(liq), CO_2(g), N_2(g), and SO_2(g). Chemical analysis of sulfur shows 67% is present as sulfides, 33% as organic sulfur, and trace amounts as sulfates.

gross heat of combustion: temperature was 25°C (77°F) and estimated standard deviation for three runs is less than 5 cal g^{-1}.

Sample I	Sample II
q_v(gross) = 2176.2 Btu lb^{-1}	q_v(gross) = 2182.0 Btu lb^{-1}
q_v(gross) = 1209.0 cal g^{-1}	q_v(gross) = 1212.2 cal g^{-1}
q_v(gross) = 5058.5 J g^{-1}	q_v(gross) = 5071.8 J g^{-1}

79CRA/ORN

OIL, SPENT SHALE; solid; Material came from the Anvil Points mine in Colorado and was ground mixed and split after experiment was completed to provide representative samples for analysis. To achieve complete combustion, samples were combined with benzoic acid in a 1:1 ratio, and combustion analysis indicated: H_2O(liq), CO_2(g), N_2(g), and SO_2(g). Chemical analysis shows that the sulfur present is primarily sulfides with traces of sulfates.

gross heat of combustion: temperature was 25°C (77°F) and estimated standard deviation for three runs is less than 5 cal g^{-1}.

Sample I	Sample II
q_v(gross) = -118.3 Btu lb^{-1}	q_v(gross) = -27.7 Btu lb^{-1}
q_v(gross) = -65.7 cal g^{-1}	q_v(gross) = -15.4 cal g^{-1}
q_v(gross) = -274.9 J g^{-1}	q_v(gross) = -64.4 J g^{-1}

79CRA/ORN

PEAT; solid; raw; highly organic soil containing partially decomposed vegetable matter and having more than 50% combustible content.

gross heat of combustion: assume values refer to room temperature; data are calculated to a dry basis.

sample 1; air-dried; moisture, 8.68%; volatile matter, 50.92%; fixed carbon, 23.79%; ash, 16.61%; sulfur, 0.99%.

q_V(gross) = 8237 Btu lb^{-1}
q_V(gross) = 4576 cal g^{-1}
q_V(gross) = 19146 J g^{-1}

18POO

sample 2; brown fibrous; air-dried; moisture, 6.34%; ash, 7.93%; sulfur, 0.69%.

q_V(gross) = 9920 Btu lb^{-1}
q_V(gross) = 5511 cal g^{-1}
q_V(gross) = 23058 J g^{-1}

sample 3; black; air-dried; moisture, 6.62%; ash, 24.44%; sulfur, 0.65%.

q_V(gross) = 7695 Btu lb^{-1}
q_V(gross) = 4275 cal g^{-1}
q_V(gross) = 17887 J g^{-1}

sample 4; brown; air-dried; moisture, 12.10%; ash, 7.22%; sulfur, 0.83%.

q_V(gross) = 8743 Btu lb^{-1}
q_V(gross) = 4857 cal g^{-1}
q_V(gross) = 20322 J g^{-1}

11DAV

Inorganic Materials

BENTONITE, PEMBINA; solid; a colloidal clay (aluminum silicate) containing a montmorillonite.

heat of dehydration: ΔH(dehydration) is derived from endotherms in the differential thermal analysis (DTA) curve, neglecting endotherms around 110°C (230°F) at which adsorbed water is evolved. Two endothermic peaks appear in the curve giving peak temperatures of 408°C (766°F) and 663°C (1225°F).

ΔH(dehydration) = 52 Btu lb^{-1}
ΔH(dehydration) = 29 cal g^{-1}
ΔH(dehydration) = 121 J g^{-1}

54ALL

BENTONITE, WYOMING; solid; a colloidal clay (aluminum silicate) containing sodium montmorillonite, which swells 12-fold when wetted with water.

heat of dehydration: approximate dehydration temperature is 675°C (124°F). ΔH(dehydration) is derived from endotherms in the differential thermal analysis (DTA) curve, neglecting endotherms around 110°C (230°F) at which adsorbed water is evolved.

ΔH(dehydration) = 79 Btu lb^{-1}
ΔH(dehydration) = 44 cal g^{-1}
ΔH(dehydration) = 184 J g^{-1}

54ALL

CEMENT HYDRATES; solid; general formula: $x\text{CaO}\cdot y\text{Al}_2\text{O}_3\cdot z\text{CaSO}_4\cdot m\text{CaCO}_3\cdot n\text{H}_2\text{O}\cdot$ (C=CaO, A=Al_2O_3, H=H_2O, Cs=CaSO_4, and Cc=CaCO_3).

heat of dehydration: gaseous water formed.

	temperature range °C	°F	moles H_2O lost	ΔH (kcal gmol^{-1})	ΔH (kJ gmol^{-1})	ΔH (Btu lb mol^{-}
$C_{3.97}AH_{11.0}$	120-200	248-392	4	48.9 ± 0.2	204.5 ± 0.8	87935 ± 3 4
	210-290	410-554	3.5	10.2 ± 0.2	42.7 ± 0.8	18361 ± 3 4
$C_{2.97}AH_{5.96}$	260-350	500-662	4.5	76.9 ± 1.8	321.7 ± 7.5	138331 ± 32 5
$C_{3.51}ACs_{2.54}H_{30.4}$	65-145	149-293	23	213.9 ± 3.1	895.0 ± 13.0	384850 ± 5590
$C_{3.14}ACs_{0.94}H_{12.1}$	95-125	203-257	1.6	2.75 ± 0.2	11.51 ± 0.8	4949 ± 3 4
	140-200	284-392	6	34.4 ± 0.7	143.9 ± 2.9	61877 ± 1247
	240-310	464-590	1.5	14.6 ± 0.6	61.1 ± 2.5	26273 ± 10 5
$C_{3.53}ACcH_{8.1}$	70-170	158-338	2	19.7 ± 2	82.4 ± 8	35432 ± 3440
	250-320	482-608	5	31.0 ± 0.5	129.7 ± 2.1	55771 ± 9 3
$C_{1.97}AH_{12.9}$	120-160	248-320	5.9	2.4 ± 0.7	10.0 ± 2.9	4300 ± 1247
	230-325	446-617	4.8	76.0 ± 5.8	318.0 ± 24.1	136740 ± 103 3
$C_{2.19}AH_{9.3}$	45-100	113-212	3	12.9 ± 2.7	54.0 ± 11.3	23220 ± 4859
	125-190	257-374	1.5	14.6 ± 2.3	61.1 ± 9.6	26273 ± 41 8
	250-300	482-572	3.5	6.0 ± 0.7	25.1 ± 2.9	10793 ± 12 7
$C_{1.07}AH_{6.3}$	120-190	248-374	2	11.2 ± 1.9	46.9 ± 7.9	20167 ± 33 7
	230-300	446-572	3	22.3 ± 1.0	93.3 ± 4.2	40119 ± 18 6
$C_{1.03}AH_{3.98}$	240-340	464-644	2.8	43.7 ± 2.7	182.8 ± 11.3	78604 ± 48 9

70HEN/STR

CLAY, CHINA; solid; Material is obtained by leaching weathered deposits of granitic rock to remove quartz and mica. Sample is composed mainly of kaolinite ($\text{Al}_2\text{O}_3.2\text{SiO}_2.2\text{H}_2\text{O}$) plus impurities.

heat of dehydration: approximate dehydration temperature is 547°C (1017°F). ΔH(dehydration) is derived from endotherms in the differential thermal analysis (DTA) curve, neglecting endotherms around 110°C (230°F) at which adsorbed water is evolved.

ΔH(dehydration) = 207 Btu lb^{-1}
ΔH(dehydration) = 115 cal g^{-1}
ΔH(dehydration) = 481 J g^{-1}

54ALL

CLAY, HALLOYSITE (DJEBEL DEBAR); solid; Material is a clay mineral with a kaolinite composition.

heat of dehydration: approximate dehydration temperature is 544°C (1011°F). ΔH(dehydration) is derived from endotherms in the differential thermal analysis (DTA) curve, neglecting endotherms around 110°C (230°F) at which adsorbed water is evolved.

ΔH(dehydration) = 164 Btu lb^{-1}
ΔH(dehydration) = 91 cal g^{-1}
ΔH(dehydration) = 381 J g^{-1}

54ALL

CLAY, K. PLASTIC KAOLIN; solid; Material is a clay mineral composed mainly of kaolinite (40% alumina, 55% silica plus impurities and water).

heat of dehydration: approximate dehydration temperature is 547°C (1017°F). ΔH(dehydration) is derived from endotherms in the differential thermal analysis (DTA) curve, neglecting endotherms around 110°C (230°F) at which adsorbed water is evolved.

ΔH(dehydration) = 187 Btu lb^{-1}
ΔH(dehydration) = 104 cal g^{-1}
ΔH(dehydration) = 435 J g^{-1}

54ALL

CLAY, MOROCCAN NO. 4; solid; Material is a kaolin type mineral composed of a hydrated aluminum silicate with generalized formula $Al_2O_3SiO_2\cdot xH_2O$, where x indicates a variable amount of water.

heat of dehydration: approximate dehydration temperature is 664°C (1227°F). ΔH(dehydration) is derived from endotherms in the differential thermal analysis (DTA) curve, neglecting endotherms around 110°C (230°F) at which adsorbed water is evolved.

ΔH(dehydration) = 41 Btu lb^{-1}
ΔH(dehydration) = 23 cal g^{-1}
ΔH(dehydration) = 96 J g^{-1}

54ALL

CLAY, NEWTON ABBOT BALL; solid; Material is a white high-plasticity burning clay composed of hydrated aluminum silicate of generalized formula $Al_2O_3SiO_2 \cdot xH_2O$, where x indicates a variable amount of water.

heat of dehydration: approximate dehydration temperature is 542°C (1008°F). ΔH(dehydration) is derived from endotherms in the differential thermal analysis (DTA) curve, neglecting endotherms around 110°C (230°F) at which adsorbed water is evolved.

$\Delta H(\text{dehydration}) = 128\ \text{Btu lb}^{-1}$
$\Delta H(\text{dehydration}) = 71\ \text{cal g}^{-1}$
$\Delta H(\text{dehydration})\ \square\ 297\ \text{J g}^{-1}$

54ALL

GLASS, PYREX; solid (Corning 7740); SiO_2, 80.66%; B_2O_3, 12.93%; Na_2O, 3.80%; Al_2O_3, 2.14%; K_2O, 0.45%.

heat content: 373-850 K (212°-1071°F)

$q_T - q_{32}\ (\text{Btu lb}^{-1}) = -170.784 + 0.2325\,(t + 459.67) + 2.44 \times 10^{-5}\,(t + 459.67)^2 - 2.619 \times 10^4\,(t + 459.67)^{-1}\ (t/°\text{F})$
$q_T - q_{273.2}\ (\text{cal g}^{-1}) = -94.88 + 0.2325\,T + 4.39 \times 10^{-5}\,T^2 + 8.083 \times 10^3\,T^{-1}\ (\text{K})$
$q_T - q_{273.2}\ (\text{J g}^{-1})\ \square\ -396.98 + 0.9728\,T + 1.837 \times 10^{-4}\,T^2 + 3.382 \times 10^4\,T^{-1}\ (\text{K})$

specific heat:

173-293 K (-148° to 68°F)

$C_p(\text{Btu lb}^{-1}\,°\text{F}^{-1}) = -0.1788 + 3.829 \times 10^{-4}\,T - 1.1728 \times 10^{-6}\,T^2$
$C_p(\text{cal g}^{-1}\,\text{K}^{-1})\ \square\ -0.245 + 2.63 \times 10^{-3}\,T - 3.80 \times 10^{-6}\,T^2$
$C_p(\text{J g}^{-1}\,\text{K}^{-1})\ \square\ -1.025 + 1.100 \times 10^{-2}\,T - 1.59 \times 10^{-5}\,T^2$

373-850 K (212°-1071°F)

$C_p(\text{Btu lb}^{-1}\,°\text{F}^{-1}) = 0.2325 + 4.878 \times 10^{-5}\,(t + 459.67) - 2.619 \times 10^4\,(t + 459.67)^{-2}$
$C_p(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.2325 + 8.78 \times 10^{-5}\,T - 8.083 \times 10^3\,T^{-2}$
$C_p(\text{J g}^{-1}\,\text{K}^{-1}) = 0.9728 + 3.674 \times 10^{-4}\,T - 3.382 \times 10^4\,T^{-2}$

68HAG/COO; 63GAT/KRE

GLASS, PYREX; liquid (Corning 7740); SiO_2, 80.66%; B_2O_3, 12.93%; Na_2O, 3.80%; Al_2O_3, 2.14%; K_2O, 0.46%.

specific heat: over the temperature range 850-1200 K (1071°-1701°F), the specific heat appears to be independent of temperature.

C_p(Btu lb^{-1} $°F^{-1}$) = 0.3471
C_p(cal g^{-1} K^{-1}) = 0.3471
C_p(J g^{-1} K^{-1}) = 1.4523

heat content: 850-1200 K (1071°-1701°F)

$q_T - q_{32}$ (Btu lb^{-1}) = $-114.55 + 0.3471\ T$ (°F)
$q_T - q_{273.2}$ (cal g^{-1}) = $-152.28 + 0.3471\ T$ (K)
$q_T - q_{273.2}$ (J g^{-1}) = $-637.14 + 1.4523\ T$ (K)

68HAG/COO

GLASS, SODA-LIME; solid (Lillie 1); SiO_2, 73.59%; Na_2O, 16.65%; CaO, 9.76%.

specific heat: 273-850 K (32°-1071°F)

C_p(Btu lb^{-1} $°F^{-1}$) = $0.1347 + 1.0733 \times 10^{-4} (t + 459.67) + 7.86 \times 10^{3} (t + 459.67)^{-2}$
C_p(cal g^{-1} K^{-1}) = $0.1347 + 1.932 \times 10^{-4}\ T + 2.423 \times 10^{3}\ T^{-2}$
C_p(J g^{-1} K^{-1}) = $0.5636 + 8.083 \times 10^{-4}\ T + 1.0138 \times 10^{4}\ T^{-2}$

heat content: 273-850 K (32°-1071°F)

$q_T - q_{32}$ (Btu lb^{-1}) = $-65.466 + 0.1347 (t + 459.67) + 5.36 \times 10^{-5} (t + 459.67)^2$
$- 7.86 \times 10^{3} (t + 459.67)^{-1}$ (t/°F)
$q_T - q_{273.2}$ (cal g^{-1}) = $-36.37 + 0.1347\ T + 9.66 \times 10^{-5}\ T^2 - 2.423 \times 10^{3}\ T^{-1}$ (K)
$q_T - q_{273.2}$ (J g^{-1}) = $-152.17 + 0.5636\ T + 4.042 \times 10^{-4}\ T^2 - 1.0138 \times 10^{4}\ T^{-1}$ (K)

68HAG/COO

GLASS, SODA-LIME; liquid (Lillie 1); SiO_2, 73.59%; Na_2O, 16.65%; CaO, 9.76%.

specific heat: over the temperature range 850 to 1200 K (1071°-1701°F), the specific heat appears to be independent of temperature.

C_p(Btu lb^{-1} $°F^{-1}$) = 0.3570
C_p(cal g^{-1} K^{-1}) = 0.3570
C_p(J g^{-1} K^{-1}) = 1.4937

heat content: 850-1200 K (1071°-1701°F)

$q_T - q_{32}$ (Btu lb^{-1}) = $-121.76 + 0.3570\ T$ (°F)
$q_T - q_{273.2}$ (cal g^{-1}) = $-158.81 + 0.3570\ T$ (K)
$q_T - q_{273.2}$ (J g^{-1}) = $-664.46 + 1.4937\ T$ (K)

68HAG/COO

GLASS, VYCOR; solid; SiO_2, 96.3%; B_2O_3, 2.9%; Al_2O_3, 0.4%; other metal oxides, 0.4%.

specific heat: 273-579 K (32°-583°F), mean values

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.16053 + 7.962 \times 10^{-5}\ T$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.12393 + 1.4333 \times 10^{-4}\ T$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.51852 + 5.9969 \times 10^{-4}\ T$

68CAM/VAN

PORCELAIN; solid; a mixture of clays, quartz, and feldspar, usually containing at least 25% aluminum. Sample 1: SiO_2, 65.14%; Al_2O_3, 28.76%; Fe_2O_3, 1.08%; K_2O, 3.61%; MgO, 1.21%; sample 2: SiO_2, 41.1%; Al_2O_3, 57.1%; Fe_2O_3, 0.3%; MgO, 0.5%; CaO, traces.

specific heat: 273-1873 K (32°-2912°F)

sample 1

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.1711 + 1.2532 \times 10^{-4}\ T - 2.3804 \times 10^{-8}\ T^2$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.10848 + 2.6497 \times 10^{-4}\ T - 7.7124 \times 10^{-8}\ T^2$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.45388 + 1.10863 \times 10^{-3}\ T - 3.2269 \times 10^{-7}\ T^2$

sample 2

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.23608 + 6.2509 \times 10^{-5}\ T - 1.7546 \times 10^{-9}\ T^2$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.20698 + 1.1542 \times 10^{-4}\ T - 5.685 \times 10^{-9}\ T^2$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.86600 + 4.8292 \times 10^{-4}\ T - 3.2319 \times 10^{-8}\ T^2$

28JAE/ROS

ZEOLITE, SILVER A; solid; synthetic ion-exchange resin; hydrated aluminum silicates containing alkali or alkaline earth metals; 90% Ag^+ relative to Na^+.

specific heat: at 310 K (98°F); nearly all water eliminated by heating in N_2 at 500°C (932°F).

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.205$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.205$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.858$

72VUC/VUC

ZEOLITE, SODIUM A; solid; synthetic ion-exchange resin; hydrated aluminum silicates containing alkali or alkaline earth metals.

specific heat: at 310 K (98°F); nearly all water eliminated by heating in N_2 at 500°C (932°F).

$C_p(\mathrm{Btu\ lb^{-1}\ {}^\circ F^{-1}}) = 0.227$
$C_p(\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.227$
$C_p(\mathrm{J\ g^{-1}\ K^{-1}}) = 0.950$

72VUC/VUC

Paper

BROWN PAPER; solid; ultimate analysis in percent by weight: carbon, 44.90%; hydrogen, 6.08%; oxygen, 47.84%; nitrogen, 0.00%; sulfur, 0.11%; ash, 1.07%; proximate analysis as received in percent by weight: moisture, 5.83%; volatile matter, 83.92%; fixed carbon, 9.24%; ash, 1.01%.

gross heat of combustion: assume values refer to room temperature.

as received	dry basis
q_V(gross) = 7261 Btu lb^{-1}	q_V(gross) = 7711 Btu lb^{-1}
q_V(gross) = 4034 cal g^{-1}	q_V(gross) = 4284 cal g^{-1}
q_V(gross) = 16877 J g^{-1}	q_V(gross) = 17924 J g^{-1}

66KAI

CORRUGATED BOX; solid; ultimate analysis in percent by weight: carbon, 43.73%; hydrogen, 5.70%; oxygen, 44.93%; nitrogen, 0.09%; sulfur, 0.21%; ash, 5.34%; proximate analysis as received in percent by weight: moisture, 5.20%; volatile matter, 77.47%; fixed carbon, 12.27%; ash, 5.06%.

gross heat of combustion: assume values refer to room temperature.

as received	dry basis
q_V(gross) = 7047 Btu lb^{-1}	q_V(gross) = 7434 Btu lb^{-1}
q_V(gross) = 3915 cal g^{-1}	q_V(gross) = 4130 cal g^{-1}
q_V(gross) = 16382 J g^{-1}	q_V(gross) = 17280 J g^{-1}

66KAI

FOOD CARTONS; solid; ultimate analysis in percent by weight: carbon, 44.74%; hydrogen, 6.10%; oxygen, 41.92%; nitrogen, 0.15%; sulfur, 0.16%; ash, 6.93%; proximate analysis as received in percent by weight: moisture, 6.11%; volatile matter, 75.59%; fixed carbon, 11.80%; ash, 6.50%.

gross heat of combustion: assume values refer to room temperature.

as received	dry basis
q_V(gross) = 7263 Btu lb^{-1}	q_V(gross) = 7735 Btu lb^{-1}
q_V(gross) = 4035 cal g^{-1}	q_V(gross) = 4297 cal g^{-1}
q_V(gross) = 16882 J g^{-1}	q_V(gross) = 17980 J g^{-1}

66KAI

JUNK MAIL; solid; ultimate analysis in percent by weight: carbon, 37.87%; hydrogen, 5.41%; oxygen, 42.74%; nitrogen, 0.17%; sulfur, 0.09%; ash, 13.72%; proximate analysis as received in percent by weight: moisture, 4.56%; volatile matter, 73.32%; fixed carbon, 9.03%; ash, 13.09%.

gross heat of combustion: assume values refer to room temperature.

as received	dry basis
q_v(gross) = 6093 Btu lb^{-1}	q_v(gross) = 6383 Btu lb^{-1}
q_v(gross) = 3385 cal g^{-1}	q_v(gross) = 3546 cal g^{-1}
q_v(gross) = 14161 J g^{-1}	q_v(gross) = 14835 J g^{-1}

66KAI

MAGAZINE; solid; ultimate analysis in percent by weight: carbon, 32.91%; hydrogen, 4.95%; oxygen, 38.55%; nitrogen, 0.07%; sulfur, 0.09%; ash, 23.43%; proximate analysis as received in percent by weight: moisture, 4.11%; volatile matter, 66.39%; fixed carbon, 7.03%; ash, 22.47%.

gross heat of combustion: assume values refer to room temperature.

as received	dry basis
q_v(gross) = 5258 Btu lb^{-1}	q_v(gross) = 5483 Btu lb^{-1}
q_v(gross) = 2921 cal g^{-1}	q_v(gross) = 3046 cal g^{-1}
q_v(gross) = 12221 J g^{-1}	q_v(gross) = 12746 J g^{-1}

66KAI

NEWSPRINT; solid; ultimate analysis in percent by weight: carbon, 49.14%; hydrogen, 6.10%; oxygen, 43.03%; nitrogen, 0.05%; sulfur, 0.16%; ash, 1.52%; proximate analysis as received in percent by weight: moisture, 5.97%; volatile matter, 81.12%; fixed carbon, 11.48%; ash, 1.43%.

gross heat of combustion: assume values refer to room temperature.

as received	dry basis
q_v(gross) = 7979 Btu lb^{-1}	q_v(gross) = 8485 Btu lb^{-1}
q_v(gross) = 4433 cal g^{-1}	q_v(gross) = 4714 cal g^{-1}
q_v(gross) = 18548 J g^{-1}	q_v(gross) = 19724 J g^{-1}

66KAI

PLASTIC COATED PAPER; solid; ultimate analysis in percent by weight: carbon, 45.30%; hydrogen, 6.17%; oxygen, 45.50%; nitrogen, 0.18%; sulfur, 0.08%; ash, 2.77%; proximate analysis as received in percent by weight: moisture, 4.71%; volatile matter, 84.20%; fixed carbon, 8.45%; ash, 2.64%.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 7346 Btu lb^{-1}	q_v(gross) = 7708 Btu lb^{-1}
q_v(gross) = 4081 cal g^{-1}	q_v(gross) = 4282 cal g^{-1}
q_v(gross) = 17075 J g^{-1}	q_v(gross) = 17917 J g^{-1}

66KAI

WAXED MILK CARTONS; solid; ultimate analysis in percent by weight: carbon, 59.18%; hydrogen, 9.25%; oxygen, 30.13%; nitrogen, 0.12%; sulfur, 0.10%; ash, 1.22%; proximate analysis as received in percent by weight: moisture, 3.45%; volatile matter, 90.92%; fixed carbon, 4.46%; ash, 1.17%.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 11330 Btu lb^{-1}	q_v(gross) = 11740 Btu lb^{-1}
q_v(gross) = 6297 cal g^{-1}	q_v(gross) = 6522 cal g^{-1}
q_v(gross) = 26347 J g^{-1}	q_v(gross) = 27289 J g^{-1}

66KAI

Plant Materials (Non-Woody)

ALGAE; solid; chlorophyll-bearing organisms occurring in both salt and fresh water; contain minerals, proteins, lipids, amino acids; a source of iodine.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

Ulva rigida (green alga)

$q_v(\text{gross}) = 6750\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 3750\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 15690\ \text{J g}^{-1}$

Fucus distichus (brown)

$q_v(\text{gross}) = 6174\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 3430\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 14351\ \text{J g}^{-1}$

Alaria nana (brown)

$q_v(\text{gross}) = 5850\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 3250\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 13598\ \text{J g}^{-1}$

71PAI

ARCHANGEL (WOOD BETONY OR BLIND NETTLE); *Stachys sylvatica*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

$q_v(\text{gross}) = 7393\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4107\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 17184\ \text{J g}^{-1}$

73PAU/BRE

BIG SAGEBRUSH; *Artemisia tridentata*; solid; Samples of current year's annual growth and woody tissue of large rangeland shrubs were collected from 11 sites in several intermountain states. Surface soil pH = 7.2 - 7.7; soil class is sand-silt loam. Mean content of current year's growth: ash, 6.7%; sulfur, 0.17%; moisture, 56%. Mean content of woody tissue: ash, 3.1%; sulfur, 0.03%; moisture, 25%.

gross heat of combustion: oven-dry weight; assume values refer to room temperature; value is mean of an average of values from 3 to 5 plants from each site.

current year's growth

$q_v(\text{gross}) = 8456\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4698\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19656\ \text{J g}^{-1}$

woody tissue

$q_v(\text{gross}) = 8350\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4639\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19410\ \text{J g}^{-1}$

82VAN/BAR

BIG SAGEBRUSH, FOLIAGE; ***Artemisia tridentata*****;** solid; freeze-dried to < 10% moisture content. Composition is ash = 7.10% and char yield = 25.7%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 9440 Btu lb^{-1}	q_v(gross) = 14350 Btu lb^{-1}
q_v(gross) = 5240 cal g^{-1}	q_v(gross) = 7970 cal g^{-1}
q_v(gross) = 21940 J g^{-1}	q_v(gross) = 33350 J g^{-1}

82SUS

BIG SAGEBRUSH, STEMS; ***Artemisia tridentata*****;** solid; Stem samples were branches less than 0.25 inch diameter with foliage removed and freeze dried to < 10% moisture content. Composition is ash = 2.83% and char yield = 27.1%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 8590 Btu lb^{-1}	q_v(gross) = 14420 Btu lb^{-1}
q_v(gross) = 4770 cal g^{-1}	q_v(gross) = 8010 cal g^{-1}
q_v(gross) = 19960 J g^{-1}	q_v(gross) = 33520 J g^{-1}

82SUS

BRACKEN FERN, FRONDS; ***Pteridium aquilinum*****;** solid; Cured samples were air-dried at room temperature. Composition is ash = 9.24% and char yield = 38.7%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 8620 Btu lb^{-1}	q_v(gross) = 13190 Btu lb^{-1}
q_v(gross) = 4790 cal g^{-1}	q_v(gross) = 7330 cal g^{-1}
q_v(gross) = 20030 J g^{-1}	q_v(gross) = 30650 J g^{-1}

82SUS

BROAD-LEAVED STITCHWORT (WOOD STARWORT); ***Stellaria nemorum***; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

$q_V(\text{gross}) = 6458$ Btu lb^{-1}
$q_V(\text{gross}) = 3588$ cal g^{-1}
$q_V(\text{gross}) = 15012$ J g^{-1}

73PAU/BRE

BULBIFEROUS TOOTHWORT (TOOTH-CRESS); ***Cardamine bulbifera***; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has a vernal (spring) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

$q_V(\text{gross}) = 7378$ Btu lb^{-1}
$q_V(\text{gross}) = 4099$ cal g^{-1}
$q_V(\text{gross}) = 17150$ J g^{-1}

73PAU/BRE

CATTAILS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 71.57, ash content = 7.90, and fixed carbon = 20.53. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 42.99, hydrogen = 5.25, oxygen = 42.47, nitrogen = 0.74, sulfur = 0.04, chlorine = 0.38, and residue (ash) = 8.13.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

$q_V(\text{gross}) = 7662$ Btu lb^{-1}
$q_V(\text{gross}) = 4257$ cal g^{-1}
$q_V(\text{gross}) = 17810$ J g^{-1}

net heat of combustion: assume values refer to room temperature.

$q_V(\text{net}) = 7017$ Btu lb^{-1}
$q_V(\text{net}) = 3898$ cal g^{-1}
$q_V(\text{net}) = 16310$ J g^{-1}

85JEN/EBE

CHEATGRASS, CURED; ***Bromus tectorum*****;** solid; Material is aerial plant air-dried at room temperature. Composition is ash = 6.46% and char yield = 21.7%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 8330 Btu lb^{-1}	q_V(gross) = 14100 Btu lb^{-1}
q_V(gross) = 4630 cal g^{-1}	q_V(gross) = 7830 cal g^{-1}
q_V(gross) = 19360 J g^{-1}	q_V(gross) = 32770 J g^{-1}

82SUS

CLOVEROOT (HERB BENNET); ***Geum urbanum*****;** solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_V(gross) = 7418 Btu lb^{-1}
q_V(gross) = 4121 cal g^{-1}
q_V(gross) = 17242 J g^{-1}

73PAU/BRE

COCKS-FOOT GRASS; ***Dactylis polygama*****;** solid; Material is a herb, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content = 12.4%, was determined at 500°C (932°F) while the temperature was increased stepwise.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature, the number of measurements is 3.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
aboveground living material				
q_V(gross) =	7636	8725	36.2	Btu lb^{-1}
q_V(gross) =	4242	4847	20.1	cal g^{-1}
q_V(gross) =	17749	20280	84.1	J g^{-1}

(more)

COCKS-FOOT GRASS - Continued

	dry weight basis	ash-free dry weight basis	std dev. of mean	
aboveground dead material				
q_v(gross) =	7306	8680	72.9	Btu lb^{-1}
q_v(gross) =	4059	4822	40.5	cal g^{-1}
q_v(gross) =	16983	20175	169	J g^{-1}
roots				
q_v(gross) =	7681	8620	85.1	Btu lb^{-1}
q_v(gross) =	4267	4789	47.3	cal g^{-1}
q_v(gross) =	17853	20037	198	J g^{-1}

75PAP

COLTSFOOT; *Tussilago farfara*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_v(gross) = 6595 Btu lb^{-1}
q_v(gross) = 3664 cal g^{-1}
q_v(gross) = 15330 J g^{-1}

73PAU/BRE

COWSLIP LUNGWORT; *Pulmonaria rubra*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_v(gross) = 7200 Btu lb^{-1}
q_v(gross) = 4000 cal g^{-1}
q_v(gross) = 16736 J g^{-1}

73PAU/BRE

DOG VIOLET; *Viola reichenbachiana*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

$q_V(\text{gross}) = 7171$ Btu lb^{-1}
$q_V(\text{gross}) = 3984$ cal g^{-1}
$q_V(\text{gross}) = 16669$ J g^{-1}

73PAU/BRE

ENCHANTER'S NIGHTSHADE; *Circaea lutetiana*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

$q_V(\text{gross}) = 7690$ Btu lb^{-1}
$q_V(\text{gross}) = 4272$ cal g^{-1}
$q_V(\text{gross}) = 17874$ J g^{-1}

73PAU/BRE

FOURWING SALTBUSH; *Atriplex canescens*; solid; Samples of current year's annual growth and woody tissue of large rangeland shrubs were collected from 7 sites in several intermountain states. Surface soil pH = 7.0 - 8.2; soil class is sand-silt loam. Mean content of current year's growth: ash, 9.9%; sulfur, 0.35%; moisture, 57.3%. Mean content of woody tissue: ash, 3.5%; sulfur, 0.08%; moisture, 29.5%.

gross heat of combustion: oven-dry weight; assume values refer to room temperature; value is mean of an average of values from 3 to 5 plants from each site.

current year's growth	woody tissue
$q_V(\text{gross}) = 7765$ Btu lb^{-1}	$q_V(\text{gross}) = 8109$ Btu lb^{-1}
$q_V(\text{gross}) = 4315$ cal g^{-1}	$q_V(\text{gross}) = 4505$ cal g^{-1}
$q_V(\text{gross}) = 18050$ J g^{-1}	$q_V(\text{gross}) = 18849$ J g^{-1}

82VAN/BAR

GALLBERRY, FOLIAGE; *Ilex glabra*; solid; freeze dried to < 10% moisture content. Composition is ash = 2.27% and char yield = 25.4%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 9960 Btu lb^{-1}	q_v(gross) = 14460 Btu lb^{-1}
q_v(gross) = 5530 cal g^{-1}	q_v(gross) = 8030 cal g^{-1}
q_v(gross) = 23140 J g^{-1}	q_v(gross) = 33610 J g^{-1}

82SUS

GERMANDER SPEEDWELL (ANGEL'S-EYE); *Veronica chamaedrys*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_v(gross) = 7783 Btu lb^{-1}
q_v(gross) = 4324 cal g^{-1}
q_v(gross) = 18092 J g^{-1}

73PAU/BRE

GLABER CRESS; *Cardamine glanduligera*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has a vernal (spring) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_v(gross) = 7574 Btu lb^{-1}
q_v(gross) = 4208 cal g^{-1}
q_v(gross) = 17606 J g^{-1}

73PAU/BRE

GRASS, LAWN CLIPPINGS; solid; ultimate analysis: carbon, 48.18%; hydrogen, 5.96%; oxygen, 36.43%; nitrogen, 4.46%; sulfur, 0.42%; ash, 6.55%; proximate analysis on an as received basis: moisture, 75.24%; volatile matter, 18.64%; fixed carbon, 4.50%; ash, 1.62%.

gross heat of combustion: assume values refer to room temperature.

dry basis	as received
$q_V(\text{gross}) = 8312$ Btu lb^{-1}	$q_V(\text{gross}) = 2059$ Btu lb^{-1}
$q_V(\text{gross}) = 4618$ cal g^{-1}	$q_V(\text{gross}) = 1144$ cal g^{-1}
$q_V(\text{gross}) = 19322$ J g^{-1}	$q_V(\text{gross}) = 4787$ J g^{-1}

66KAI

GREASEWOOD; *Sarcobatus vermiculatus*; solid; Samples of current year's annual growth and woody tissue of large rangeland shrubs were collected from 3 sites in several intermountain states. Surface soil pH = 7.9 - 9.5; soil class is sandy loam-clay loam. Mean content of current year's growth: ash, 20.2%; sulfur, 0.46%; moisture, 0.46%. Mean content of woody tissue: ash, 1.7%; sulfur, 0.24%; moisture, 34.0%.

gross heat of combustion: oven-dry weight; assume values refer to room temperature; value is mean of an average of values from 3 to 5 plants from each site.

current year's growth	woody tissue
$q_V(\text{gross}) = 6599$ Btu lb^{-1}	$q_V(\text{gross}) = 8507$ Btu lb^{-1}
$q_V(\text{gross}) = 3666$ cal g^{-1}	$q_V(\text{gross}) = 4726$ cal g^{-1}
$q_V(\text{gross}) = 15339$ J g^{-1}	$q_V(\text{gross}) = 19774$ J g^{-1}

82VAN/BAR

HERB ROBERT (RED ROBIN); *Geranium robertianum*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

$q_V(\text{gross}) = 7112$ Btu lb^{-1}
$q_V(\text{gross}) = 3951$ cal g^{-1}
$q_V(\text{gross}) = 16531$ J g^{-1}

73PAU/BRE

HERBS, ALPINE TUNDRA; solid; Samples of 20 species of herbs were collected in the alpine tundra of Mt. Washington, N.H. Mean lipid content was 1.43 ± 0.1% of volatile-free dry weight. Samples ground and oven-dried at 80°C (176°F).

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

$q_V(\text{gross}) = 8282 \pm 52$ Btu lb^{-1}
$q_V(\text{gross}) = 4601 \pm 29$ cal g^{-1}
$q_V(\text{gross}) = 19251 \pm 121$ J g^{-1}

62BLI

IDAHO FESCUE, CURED; ***Festuca idahoensis***; solid; Material is aerial plant air dried at room temperature. Composition is ash = 9.45% and char yield = 24.6%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
$q_V(\text{gross}) = 8670$ Btu lb^{-1}	$q_V(\text{gross}) = 14340$ Btu lb^{-1}
$q_V(\text{gross}) = 4820$ cal g^{-1}	$q_V(\text{gross}) = 7970$ cal g^{-1}
$q_V(\text{gross}) = 20160$ J g^{-1}	$q_V(\text{gross}) = 33340$ J g^{-1}

82SUS

IRISH SHAMROCK (EUROPEAN WOOD SORREL); ***Oxalis acetosella***; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

$q_V(\text{gross}) = 7783$ Btu lb^{-1}
$q_V(\text{gross}) = 4324$ cal g^{-1}
$q_V(\text{gross}) = 18092$ J g^{-1}

73PAU/BRE

JUPITER'S-DISTAFF; *Salvia glutinosa*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_V(gross) = 8158 Btu lb^{-1}
q_V(gross) = 4532 cal g^{-1}
q_V(gross) = 18962 J g^{-1}

73PAU/BRE

LADY FERN; *Athyrium filix-femina*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_V(gross) = 7335 Btu lb^{-1}
q_V(gross) = 4075 cal g^{-1}
q_V(gross) = 17050 J g^{-1}

73PAU/BRE

LETTUCE MURALIS; *Mycelis muralis*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_V(gross) = 8042 Btu lb^{-1}
q_V(gross) = 4468 cal g^{-1}
q_V(gross) = 18694 J g^{-1}

73PAU/BRE

MALE FERN; *Dryopteris filix-mas*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_v(gross) = 7808 Btu lb^{-1}
q_v(gross) = 4338 cal g^{-1}
q_v(gross) = 18150 J g^{-1}

73PAU/BRE

MEADOW-RUE ISOPYRUM; *Isopyrum thalictroides*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has a vernal (spring) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_v(gross) = 7969 Btu lb^{-1}
q_v(gross) = 4427 cal g^{-1}
q_v(gross) = 18523 J g^{-1}

73PAU/BRE

MELIC GRASS; *Melica uniflora*; solid; Material is a herb, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content was determined at 500°C (932°F) while the temperature was increased stepwise. Ash content of aboveground living material = 8.1%; aboveground dead material = 12.2%; roots = 7.6%.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature, the number of measurements is 3.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
aboveground living material				
q_v(gross) =	7709	8397	7.7	Btu lb^{-1}
q_v(gross) =	4283	4665	4.3	cal g^{-1}
q_v(gross) =	17920	19518	18	J g^{-1}

(more)

MELIC GRASS - Continued

	dry weight basis	ash-free dry weight basis	std dev. of mean	
aboveground dead material				
q_V(gross) =	7657	8730	57.6	Btu lb^{-1}
q_V(gross) =	4254	4850	32.0	cal g^{-1}
q_V(gross) =	17799	20292	134	J g^{-1}
roots				
q_V(gross) =	7972	8631	15	Btu lb^{-1}
q_V(gross) =	4429	4795	8.5	cal g^{-1}
q_V(gross) =	18531	20062	36	J g^{-1}

75PAP

MERCURIALIS PERENNIS; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period, and is a European poisonous plant with the foliage yielding an unstable blue dye.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_V(gross) = 6709 Btu lb^{-1}
q_V(gross) = 3727 cal g^{-1}
q_V(gross) = 15594 J g^{-1}

73PAU/BRE

MOSSES, ALPINE TUNDRA; solid; Samples of 7 species of mosses were collected in the alpine tundra of Mt. Washington, N.H. Mean lipid content was 1.0% of the volatile-free dry weight. Samples were ground and air-dried at 80°C (176°F).

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

q_V(gross) = 7938 ± 130 Btu lb^{-1}
q_V(gross) = 4410 ± 70 cal g^{-1}
q_V(gross) = 18450 ± 293 J g^{-1}

62BLI

MOUNTAIN RUSH; *Carex montana*; solid; Material is a herb, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content was determined at 500°C (932°F) while the temperature was increased stepwise. Ash content of aboveground living material = 8.4%; aboveground dead material = 14.7%; roots = 6.3%.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature, the number of measurements is 3.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
aboveground living material				
q_V(gross) =	7580	8689	5.6	Btu lb^{-1}
q_V(gross) =	4222	4827	3.1	cal g^{-1}
q_V(gross) =	17667	20196	13	J g^{-1}
aboveground dead material				
q_V(gross) =	7092	8305	13.2	Btu lb^{-1}
q_V(gross) =	3940	4614	73.5	cal g^{-1}
q_V(gross) =	16485	19305	308	J g^{-1}
roots				
q_V(gross) =	8042	8575	140	Btu lb^{-1}
q_V(gross) =	4468	4764	77.5	cal g^{-1}
q_V(gross) =	18694	19933	324	J g^{-1}

75PAP

PLANTS, FLOWER GARDEN; solid; ultimate analysis: carbon, 46.65%; hydrogen, 6.61%; oxygen, 40.18%; nitrogen, 1.21%; sulfur, 0.26%; ash, 5.09%; proximate analysis as received: moisture, 53.94%; volatile matter, 35.64%; fixed carbon, 8.08%; ash, 2.34%.

gross heat of combustion: assume values refer to room temperature.

as received	dry basis
q_V(gross) = 3699 Btu lb^{-1}	q_V(gross) = 8032 Btu lb^{-1}
q_V(gross) = 2055 cal g^{-1}	q_V(gross) = 4462 cal g^{-1}
q_V(gross) = 8599 J g^{-1}	q_V(gross) = 18671 J g^{-1}

66KAI

PLANTS, VASCULAR AQUATIC; solid; plants taken from Par Pond, U.S. AEC Savannah River Plant, near Aiken, S.C.; samples dried at 60°C (140°F) and pulverized to pass 40 mesh screen.

gross heat of combustion: assume values refer to room temperature.

	Protein Content		q_v(gross)	
Species	g (100 g dry wt.)	(Btu lb^{-1})	(cal g^{-1})	(J g^{-1})
Typha latifolia	4.0	7672	4262	17832
Hydrotrida carolinensis	10.5	7304	4058	16979
Brasenia schreberi	10.9	7247	4026	16845
Utricularia inflata	11.4	7241	4023	16832
Nelumbo lutea	12.1	7609	4227	17686
Myriophyllum heterophyllum	13.5	7130	3961	16573
Eleocharis acicularis	14.1	7661	4256	17807
Najas guadalupensis	14.4	7052	3918	16393
Nymphaea odorata	14.6	7524	4180	17489
Ceratophyllum demensum	17.1	7031	3906	16343
Nuphar advena	21.6	7767	4315	18054

70BOY

RUBBER RABBITBRUSH; *Chrysothamnus nauseosus*; solid; Samples of current year's annual growth and woody tissue of large rangeland shrubs were collected from 6 sites in several intermountain states. Surface soil pH = 7.5 - 7.9; solid class is sandy-clay loam. Mean content of current year's growth: ash, 7.4%; sulfur, 0.20%; moisture, 55.0%. Mean content of woody tissue: ash, 2.7%; sulfur, 0.04%; moisture, 44.7%.

gross heat of combustion: oven-dry weight; assume values refer to room temperature; value is mean of an average of values from 3 to 5 plants from each site.

current year's growth	woody tissue
q_v(gross) = 8698 Btu lb^{-1}	q_v(gross) = 8420 Btu lb^{-1}
q_v(gross) = 4832 cal g^{-1}	q_v(gross) = 4678 cal g^{-1}
q_v(gross) = 20217 J g^{-1}	q_v(gross) = 19573 J g^{-1}

82VAN/BAR

SAW-PALMETTO, FRONDS; *Serenoa repens*; solid; Samples were freeze dried to < 10% moisture content. Composition is ash = 5.37% and char yield = 33.3%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 9150 Btu lb^{-1}	q_v(gross) = 13890 Btu lb^{-1}
q_v(gross) = 5080 cal g^{-1}	q_v(gross) = 7720 cal g^{-1}
q_v(gross) = 21270 J g^{-1}	q_v(gross) = 32290 J g^{-1}

82SUS

SEDGE GRASS; *Carex michelii*; solid; Material is a herb, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content was determined at 500°C (932°F) while the temperature was increased stepwise. Ash content of aboveground living material = 9.0%; aboveground dead material = 10.6%; roots = 8.3%.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature, the number of measurements is 3.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
aboveground living material				
q_V(gross) =	7817	8492	6.3	Btu lb^{-1}
q_V(gross) =	4343	4718	3.5	cal g^{-1}
q_V(gross) =	18171	19740	15	J g^{-1}
aboveground dead material				
q_V(gross) =	7893	8827	38.7	Btu lb^{-1}
q_V(gross) =	4385	4904	21.5	cal g^{-1}
q_V(gross) =	18347	20518	90.0	J g^{-1}
roots				
q_V(gross) =	7983	8707	67.1	Btu lb^{-1}
q_V(gross) =	4435	4837	37.3	cal g^{-1}
q_V(gross) =	18556	20238	156	J g^{-1}

75PAP

SHRUBS, DECIDUOUS; ALPINE TUNDRA; solid; Samples of 9 species of shrubs were collected in the alpine tundra of Mt. Washington, N.H. Mean lipid content was 1.97 ± 0.3% of the volatile-free dry weight. Samples were ground and oven-dried at 80°C (176°F).

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

q_V(gross) = 8878 ± 89 Btu lb^{-1}
q_V(gross) = 4932 ± 33 cal g^{-1}
q_V(gross) = 20635 ± 138 J g^{-1}

62BLI

SHRUBS, EVERGREEN; ALPINE TUNDRA; solid; Samples of 11 species of shrubs were collected in the alpine tundra of Mt. Washington, N.H. Mean lipid content was 3.72 ± 0.5% of the volatile-free dry weight. Samples were ground and oven-dried at 80°C (176°F).

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

$q_v(\text{gross}) = 9176 \pm 86$ Btu lb^{-1}
$q_v(\text{gross}) = 5098 \pm 48$ cal g^{-1}
$q_v(\text{gross}) = 21330 \pm 201$ J g^{-1}

62BLI

SHRUBS, EVERGREEN; CUTTINGS; solid; ultimate analysis: carbon, 48.51%; hydrogen, 6.54%; oxygen, 40.44%; nitrogen, 1.71%; sulfur, 0.19%; ash, 2.61%; proximate analysis as received: moisture, 69.00%; volatile matter, 25.18%; fixed carbon, 5.01%; ash, 0.81%.

gross heat of combustion: assume values refer to room temperature.

as received	dry basis
$q_v(\text{gross}) = 2709$ Btu lb^{-1}	$q_v(\text{gross}) = 8741$ Btu lb^{-1}
$q_v(\text{gross}) = 1505$ cal g^{-1}	$q_v(\text{gross}) = 4856$ cal g^{-1}
$q_v(\text{gross}) = 6299$ J g^{-1}	$q_v(\text{gross}) = 20318$ J g^{-1}

66KAI

SOW-TEAT STRAWBERRY (WOODLAND STRAWBERRY); ***Fragaria vesca***; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

$q_v(\text{gross}) = 7538$ Btu lb^{-1}
$q_v(\text{gross}) = 4188$ cal g^{-1}
$q_v(\text{gross}) = 17523$ J g^{-1}

73PAU/BRE

SPREADING RABBITBRUSH; ***Chrysothamnus linifolius*****;** solid; Samples of current year's annual growth and woody tissue of large rangeland shrubs were collected from 2 sites in several intermountain states. Surface soil pH = 7.3 - 7.7; soil class is loamy sand-silt loam. Mean moisture content of current year's growth, 59.2%; of woody tissue, 52.7%.

gross heat of combustion: oven-dry weight; assume values refer to room temperature; value is mean of an average of values from 3 to 5 plants from each site.

current year's growth	woody tissue
$q_V(\text{gross}) = 8062\ \text{Btu lb}^{-1}$	$q_V(\text{gross}) = 8206\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 4479\ \text{cal g}^{-1}$	$q_V(\text{gross}) = 4559\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 18740\ \text{J g}^{-1}$	$q_V(\text{gross}) = 19075\ \text{J g}^{-1}$

82VAN/BAR

SPURGE ALMOND; ***Euphorbia amygdaloides*****;** solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

$q_V(\text{gross}) = 8069\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 4483\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 18757\ \text{J g}^{-1}$

73PAU/BRE

STINGING NETTLE; *Urtica diocia*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

$q_V(\text{gross}) = 6847\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 3804\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 15916\ \text{J g}^{-1}$

73PAU/BRE

SUDAN GRASS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 72.75, ash content = 8.65, and fixed carbon = 18.60. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 44.58, hydrogen = 5.35, oxygen = 39.18, nitrogen = 1.21, sulfur = 0.08, chlorine = 0.13, and residue (ash) = 9.47.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 7447 Btu lb^{-1}
q_v(gross) = 4156 cal g^{-1}
q_v(gross) = 17390 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7017 Btu lb^{-1}
q_v(net) = 3898 cal g^{-1}
q_v(net) = 16310 J g^{-1}

85JEN/EBE

SWEET WOODRUFF; *Galium odoratum*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_v(gross) = 7281 Btu lb^{-1}
q_v(gross) = 4045 cal g^{-1}
q_v(gross) = 16924 J g^{-1}

73PAU/BRE

TALL OXEYE; *Telekia speciosa*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_v(gross) = 7634 Btu lb^{-1}
q_v(gross) = 4241 cal g^{-1}
q_v(gross) = 17744 J g^{-1}

73PAU/BRE

TOUCH-ME-NOT; *Impatiens noli-tangere*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_v(gross) = 7963 Btu lb^{-1}
q_v(gross) = 4424 cal g^{-1}
q_v(gross) = 18510 J g^{-1}

73PAU/BRE

WHITE BUTTERBUR; *Petasites albus*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_v(gross) = 6802 Btu lb^{-1}
q_v(gross) = 3779 cal g^{-1}
q_v(gross) = 15811 J g^{-1}

73PAU/BRE

WINDFLOWER (WOOD ANEMONE); *Anemone nemorosa*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has a vernal (spring) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_v(gross) = 8134 Btu lb^{-1}
q_v(gross) = 4519 cal g^{-1}
q_v(gross) = 18907 J g^{-1}

73PAU/BRE

WOOD BLUEGRASS; *Poa nemoralis*; solid; Material is a herb, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content was determined at 500°C (932°F) while the temperature was increased stepwise. Ash content of aboveground living material = 6.0%; aboveground dead material = 8.7%; roots = 11.0%.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature, the number of measurements is 3.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
aboveground living material				
q_V(gross) =	7884	8390	56.3	Btu lb^{-1}
q_V(gross) =	4380	4661	31.3	cal g^{-1}
q_V(gross) =	18326	19502	131	J g^{-1}
aboveground dead material				
q_V(gross) =	7888	8636	27.0	Btu lb^{-1}
q_V(gross) =	4382	4798	15.0	cal g^{-1}
q_V(gross) =	18334	20075	62.8	J g^{-1}
roots				
q_V(gross) =	8050	9025	82.6	Btu lb^{-1}
q_V(gross) =	4472	5014	45.9	cal g^{-1}
q_V(gross) =	18711	20979	192	J g^{-1}

75PAP

WOOD SEDGE; *Carex sylvatica*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

q_V(gross) = 7515 Btu lb^{-1}
q_V(gross) = 4175 cal g^{-1}
q_V(gross) = 17468 J g^{-1}

73PAU/BRE

YELLOW ARCHANGEL (DEAD NETTLE); *Lamium galeobdolon*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has an aestival (summer) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

$q_v(\text{gross}) = 7879\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4377\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 18313\ \text{J g}^{-1}$

73PAU/BRE

YELLOW WOOD ANEMONE; *Anemone ranunculoides*; solid; Material is an integral part of the ecosystem at the herbaceous layer level of the mixed fir and beech forest in the Pulmonario (rubro) Abieti-Fagetum area of the Bucegi mountains (two different stations) in Romania. The plants have the following constitution: 33% of the weight is represented by the stem axis and 67% by leaves. The species has a vernal (spring) type vegetation period.

gross heat of combustion: assume values refer to room temperature and values are calculated to a dry basis.

$q_v(\text{gross}) = 8158\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4532\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 18962\ \text{J g}^{-1}$

73PAU/BRE

Polymers and Plastics

ARALDITE; solid; proprietary trade name for a series of epoxy resins used for casting, encapsulating, laminating, surface coating and as an adhesive.

specific heat:

temperature				
(K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
1.5	-456.7	0.000014	0.000014	0.00006
2	-455.8	0.000057	0.000057	0.00024
3	-454	0.00021	0.00021	0.00089
4	-452	0.0054	0.0054	0.00225
6	-448.6	0.0020	0.0020	0.0082
8	-445	0.0040	0.0040	0.0169
10	-441.4	0.0065	0.0065	0.0272
15	-432.4	0.0130	0.0130	0.0542
20	-423.4	0.0194	0.0194	0.0811

54PAR/QUA

BAKELITE VARNISH, FORMITE VIII05; solid; trademark for synthetic resin of the phenol-formaldehyde type.

specific heat:

temperature				
(K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
4	-452	0.0011	0.0011	0.0046
6	-448.6	0.0021	0.0021	0.0086
8	-445	0.0032	0.0032	0.0134
10	-441.4	0.0046	0.0046	0.0192
15	-432.4	0.0100	0.0100	0.0418
20	-423.4	0.0159	0.0159	0.0667
30	-405.4	0.029	0.029	0.121
40	-387.4	0.043	0.043	0.179
50	-369.4	0.057	0.057	0.237
70	-333.4	0.083	0.083	0.347
90	-297.4	0.017	0.017	0.449

53HIL/SMI

BUTADIENE-STYRENE COPOLYMER, GL-622; solid; composition: carbon, 90.100%; hydrogen, 9.170%; sulfur, 0.081%; oxygen, 0.14%; ash, 0.111%; styrene, 42.98%; phenyl-β-naphthylamine, 0.1%; polymerized at 50°C (122°F).

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
5	-450	0.00081	0.00081	0.0034
50	-370	0.076	0.076	0.318
100	-280	0.136	0.136	0.569
150	-190	0.190	0.190	0.794
200	-100	0.244	0.244	1.022
220	- 64	0.268	0.268	1.122
255	- 1	0.405	0.405	1.694

for temperature range: 255-330 K (0°-135°F)

$C_p(\text{Btu lb}^{-1}\,{}^\circ\text{F}^{-1}) = 0.506 + 2.77 \times 10^{-5}\,T + 3.688 \times 10^{-7}\,T^2$

$C_p(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.316 + 4.37 \times 10^{-5}\,T + 1.195 \times 10^{-6}\,T^2$

$C_p(\text{J g}^{-1}\,\text{K}^{-1}) = 1.322 + 1.83 \times 10^{-4}\,T + 5.000 \times 10^{-6}\,T^2$

55FUR/McC

BUTADIENE-STYRENE COPOLYMER, X-454; solid; composition: carbon, 88.869%; hydrogen, 10.872%; sulfur, 0.056%; oxygen, 0.235%; ash, 0.18%; styrene, 8.58%; phenyl-β-naphthylamine, 0.1%; polymerized at 5°C (36°F).

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
50	-370	0.084	0.084	0.351
100	-280	0.153	0.153	0.464
150	-190	0.220	0.220	0.92
200	-100	0.373	0.373	1.56
250	- 10	0.423	0.423	1.77
300	80	0.464	0.464	1.94
330	134	0.485	0.485	2.03

53bFUR/McC

BUTADIENE-STYRENE COPOLYMER, X-478; solid; composition: carbon, 89.443%; hydrogen, 10.4008%; sulfur, 0.048%; oxygen, 0.15%; ash, 0.098%; styrene, 22.61%; phenyl-β-naphthylamine, 0.1%; polymerized at 5°C (41°F).

specific heat:

temperature (K)	 (°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
15	-433	0.016	0.016	0.067
50	-370	0.081	0.081	0.338
100	-280	0.147	0.147	0.617
150	-190	0.209	0.209	0.874
195	-109	0.262	0.262	1.096
225	- 55	0.405	0.405	1.693

225-330 K (-54° to 135°F)

$$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.4228 + 3.812 \times 10^{-5}\ T + 3.483 \times 10^{-7}\ T^2$$
$$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.3337 + 6.29 \times 10^{-5}\ T + 1.1205 \times 10^{-6}\ T^2$$
$$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 1.396 + 2.632 \times 10^{-4}\ T + 4.6882 \times 10^{-6}\ T^2$$

55FUR/McC

BUTENE-1-POLYSULFONE; solid; repeating unit: $C_4H_8O_2S$.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 10347 ± 6.8 Btu lb^{-1}
q_v(gross) = 5748.3 ± 3.8 cal g^{-1}
q_v(gross) = 24050.9 ± 15.9 J g^{-1}

59IVI/KEI

cis-BUTENE-2-POLYSULFONE; solid; repeating unit: $C_4H_8O_2S$.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 10340 ± 4.7 Btu lb^{-1}
q_v(gross) = 5744.6 ± 2.6 cal g^{-1}
q_v(gross) = 24035.4 ± 10.9 J g^{-1}

59IVI/KEI

trans-BUTENE-2-POLYSULFONE; solid; repeating unit: $C_4H_8O_2S$.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 10342 ± 4.5 Btu lb^{-1}
q_v(gross) = 5745.7 ± 2.5 cal g^{-1}
q_v(gross) = 24040.0 ± 10.5 J g^{-1}

59IVI/KEI

iso-BUTENE POLYSULFONE (2-methylpropene polysulfone); solid; repeating unit: $C_4H_8O_2S$.

gross heat of combustion: at 25°C (77°F)

$q_V(\text{gross}) = 10356 \pm 5.2$ Btu lb^{-1}
$q_V(\text{gross}) = 5753.2 \pm 2.9$ cal g^{-1}
$q_V(\text{gross}) = 24071.4 \pm 12.1$ J g^{-1}

59IVI/KEI

CELLULOID; solid; Celanese Corp. of America trade name; a solid solution of cellulose nitrate and camphor or other related plasticizers.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 7603$ Btu lb^{-1}
$q_V(\text{gross}) = 4224$ cal g^{-1}
$q_V(\text{gross}) = 17673$ J g^{-1}

15ROT/WAL

DELRIN; solid; (polyoxymethylene); E.I. duPont de Nemours and Company trade name; crystallized resin granules, 99.3%; unspecified organic additives, 0.7%; repeating unit: CH_2O.

gross heat of combustion: at 25°C (77°F)

$q_V(\text{gross}) = 7284.8 \pm 1$ Btu lb^{-1}
$q_V(\text{gross}) = 4047.1 \pm 0.8$ cal g^{-1}
$q_V(\text{gross}) = 16933.3 \pm 3.3$ J g^{-1}

63PAR/MOS

DICYANDIAMIDE (TECHNICAL); solid; elementary analysis: carbon, 28.97%; hydrogen, 4.44%; nitrogen, 66.60%; formula $C_2H_4N_4$.

gross heat of combustion: at 25°C (77°F)

unhardened	hardened
$q_V(\text{gross}) = 6723.7 \pm 3.1$ Btu lb^{-1}	$q_V(\text{gross}) = 6772.3 \pm 3.8$ Btu lb^{-1}
$q_V(\text{gross}) = 3735.4 \pm 1.7$ cal g^{-1}	$q_V(\text{gross}) = 3762.4 \pm 2.1$ cal g^{-1}
$q_V(\text{gross}) = 15628.9 \pm 7.1$ J g^{-1}	$q_V(\text{gross}) = 15741.9 \pm 8.8$ J g^{-1}

67FRA/MIS

DURETHAN U20; solid; a polyurethane from 1,4-butanediol and hexamethyldiisocyanate; formula $C_{12}H_{22}O_4N_2$.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 11199 ± 3.4 Btu lb^{-1}
q_v(gross) = 6221.4 ± 1.9 cal g^{-1}
q_v(gross) = 26030.3 ± 7.9 J g^{-1}

67FRA/MIS

EPILOX EG1, HARDENED; solid; empirical formula $C_{39}H_{40}O_{8.5}$; the unhardened resin plus phthalic anhydride.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 13021 ± 3.4 Btu lb^{-1}
q_v(gross) = 7233.9 ± 1.9 cal g^{-1}
q_v(gross) = 30266.6 ± 7.9 J g^{-1}

67FRA/MIS

EPILOX EG1, UNHARDENED; solid; elementary analysis: carbon, 74.74%; hydrogen, 7.27%; oxygen, 17.99%; a diepoxide from epichlorhydrin plus 4,4'-dihydroxydiphenyl-2,2'-propane; empirical formula $C_{31}H_{36}O_{5.5}$.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 14161 ± 4.5 Btu lb^{-1}
q_v(gross) = 7867.0 ± 2.5 cal g^{-1}
q_v(gross) = 32915.5 ± 10.5 J g^{-1}

67FRA/MIS

GLYPTAL; solid; trademark for synthetic resins and plasticizers prepared from a polyhydric alcohol and phthalic anhydride.

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
1	-457.6	0.0000072	0.0000072	0.00003
2	-455.8	0.000048	0.000048	0.0002
3	-454	0.0002	0.0002	0.0007
4	-452	0.0005	0.0005	0.002
6	-448.6	0.002	0.002	0.007
8	-445	0.003	0.003	0.014
10	-441.4	0.005	0.005	0.02
15	-432.4	0.014	0.014	0.06
20	-423.4	0.03	0.03	0.11
30	-405.4	0.05	0.05	0.20
40	-387.4	0.07	0.07	0.29
60	-351.4	0.12	0.12	0.49
80	-315.4	0.19	0.19	0.79
100	-279.4	0.275	0.275	1.15

59KEE/SEI

LUCITE; solid; (polymethylmethacrylate); (E.I. duPont de Nemours and Company trade name); repeating unit: $C_5H_8O_2$.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 11462 ± 4.1 Btu lb^{-1}
q_v(gross) = 6367.8 ± 2.3 cal g^{-1}
q_v(gross) = 26642.9 ± 9.6 J g^{-1}

specific heat: assume values refer to room temperature.

C_p(Btu lb^{-1} $°F^{-1}$) = 0.343
C_p(cal g^{-1} K^{-1}) = 0.343
C_p(J g^{-1} K^{-1}) = 1.435

67FRA/MIS; 38GUC/FOR

MELINEX FILM; solid; Material measured was a polyester 0.001 in. thick, with an empirical formula $(C_{10}H_8O_4)_n$.

gross heat of combustion: temperature = 298.15 K (77°F), pressure = 30 atm oxygen, result had a mean CO_2 recovery of 99.746%.

q_v(gross) = 9864.3 ± 2.6 Btu lb^{-1}
q_v(gross) = 5480.1 ± 1.4 cal g^{-1}
q_v(gross) = 22928.9 ± 6 J g^{-1}

75AND/BAR

2,5-METHYLOLMELAMINE, HARDENED; solid; elementary analysis: carbon, 34.19%; hydrogen, 5.27%; oxygen, 17.07%; nitrogen, 43.47%; empirical formula $C_{11}H_{20}O_4N_{12}$; a melamine-formaldehyde polymer.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 6950.9 ± 2.3 Btu lb^{-1}
q_v(gross) = 3861.6 ± 1.3 cal g^{-1}
q_v(gross) = 16156.9 ± 5.4 J g^{-1}

67FRA/MIS

2,5-METHYLOLMELAMINE, UNHARDENED; solid; elementary analysis: carbon, 32.70%; hydrogen, 5.53%; oxygen, 20.51%; nitrogen, 41.26%; empirical formula $C_{5.5}H_{11}O_{2.5}N_6$; a melamine-formaldehyde polymer.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 6699.2 ± 2.2 Btu lb^{-1}
q_v(gross) = 3721.8 ± 1.2 cal g^{-1}
q_v(gross) = 15572.0 ± 5.0 J g^{-1}

67FRA/MIS

MYLAR FILM; solid; E. I. duPont de Nemours and Company trade name; Repeating unit is $(C_{12}H_{12}O_4)_n$. Material measured was 100-gauge, type A polyester film and is a copolymer of ethylene glycol and terephthalic acid.

gross heat of combustion: temperature = 25°C (77°F), oxygen pressure = 30 atm, value given is expressed as a function of humidity (where RH is relative humidity in %).

q_v(gross) = -9862.74 + 0.4543RH Btu lb^{-1}
q_v(gross) = -5479.30 + 0.2524RH cal g^{-1}
q_v(gross) = -22925.39 + 1.0560RH J g^{-1}

70MAN/RAP

NORYL RESIN III; solid; (E.I. duPont de Nemours and Company trade name); composition: polystyrene, 47%; polyphenylene oxide, 47%; polybutadiene, 5%; polyethylene, 1%.

heat of fusion: 83°-103°C (181°-217°F)

$L_f = 0.4$ Btu lb^{-1}
$L_f = 0.2$ cal g^{-1}
$L_f = 0.8$ J g^{-1}

specific heat:

temperature				
(K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
194	-110	0.178	0.178	0.745
277	39	0.242	0.242	1.013
298	77	0.282	0.282	1.205
323	122	0.316	0.316	1.322
373	212	0.393	0.393	1.644
424	304	0.439	0.439	1.837
482	408	0.483	0.483	2.021
519	475	0.503	0.503	2.105

specific heat change at glass transition temperature:

temperature				
(K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
212	- 78	0.005	0.005	0.021
414	286	0.044	0.044	0.184

70BAI

NYLON-6; solid; (poly-ε-caprolactam); repeating unit: $C_6H_{11}NO$.

gross heat of combustion: at 20°C (68°F)

slow condensation	rapid condensation
$q_v(\text{gross}) = 13640\ \text{Btu lb}^{-1}$	$q_v(\text{gross}) = 13660\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 7575\ \text{cal g}^{-1}$	$q_v(\text{gross}) = 7587\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 31694\ \text{J g}^{-1}$	$q_v(\text{gross}) = 31744\ \text{J g}^{-1}$

Miramid H: 25°C (77°F)

$q_v(\text{gross}) = 13417 \pm 5.0\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 7454.1 \pm 2.8\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 31188.0 \pm 11.7\ \text{J g}^{-1}$

specific heat: 273-433 K (32°-320°F); amorphous nylon-6.

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = -0.047 + 8.3 \times 10^{-4}\ T$
$C_p(\text{cal g}^{-1}\ \text{deg}^{-1}) = -0.085 + 1.5 \times 10^{-3}\ T$
$C_p(\text{J g}^{-1}\ \text{deg}^{-1}) = -0.356 + 6.3 \times 10^{-3}\ T$

melting point: maximum melting temperature is 225°C (437°F)

heat of fusion: at 225°C (437°F)

$L_f = 81\ \text{Btu lb}^{-1}$
$L_f = 45\ \text{cal g}^{-1}$
$L_f = 188\ \text{J g}^{-1}$

57KAC; 55MAR/SMI; 67FRA/MIS

NYLON-6; liquid; (poly-ε-caprolactam); repeating unit: $C_6H_{11}NO$.

specific heat: 433-553 K (320°-536°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.5708 + 1.867 \times 10^{-4}\ T$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.485 + 3.36 \times 10^{-4}\ T$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 2.029 + 1.406 \times 10^{-3}\ T$

55MAR/SMI

NYLON-6,6; solid; (polyhexamethyleneadipamide); repeating unit: $C_{12}H_{22}N_2O_2$; average mol. wt. 11000.

gross heat of combustion: at 20°C (68°F)

q_v(gross) = 13650 Btu lb^{-1}
q_v(gross) = 7581 cal g^{-1}
q_v(gross) = 31719 J g^{-1}

Ultramid A

q_v(gross) = 13579 ± 4.3 Btu lb^{-1}
q_v(gross) = 7543.8 ± 2.4 cal g^{-1}
q_v(gross) = 31563.3 ± 10.0 J g^{-1}

specific heat: 273-553 K (32°-536°F)

Annealed Sample

(K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
273	32	0.311	0.311	1.301
293	68	0.333	0.333	1.393
313	104	0.367	0.367	1.536
333	140	0.424	0.424	1.774
353	176	0.468	0.468	1.958
373	212	0.505	0.505	2.113
393	248	0.548	0.548	2.293
413	284	0.583	0.583	2.439
433	320	0.642	0.642	2.686
453	356	0.620	0.620	2.594
473	392	0.646	0.646	2.703
493	428	0.664	0.664	2.778
513	464	0.80	0.80	3.347
523	482	1.13	1.13	4.728
533	500	2.75	2.75	11.51
543	518	1.3	1.3	5.439
553	536	0.75	0.75	3.138

Drawn Sample

(K)	(°F)			
273	32	0.302	0.302	1.264
293	68	0.345	0.345	1.443
313	104	0.376	0.376	1.573
333	140	0.420	0.420	1.757
353	176	0.458	0.458	1.916

(more)

NYLON-6,6 - Continued

Drawn Sample (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
373	212	0.479	0.479	2.004
393	248	0.503	0.503	2.105
413	284	0.528	0.528	2.209
433	320	0.542	0.542	2.268
453	356	0.560	0.560	2.343
473	392	0.582	0.582	2.435
493	428	0.567	0.567	2.372
513	464	0.676	0.676	2.828
523	482	1.55	1.55	6.485
533	500	6.5	6.5	27.20
543	518	1.35	1.35	5.648
553	536	0.75	0.75	3.138

melting point:

	Drawn Filaments	Annealed
M.P., °C	259	262
M.P., °F	498	504
Melting Range, °C	18	30
Melting Range, °F	32	54

heat of fusion:

	Drawn Filaments	Annealed
L_f(Btu lb^{-1})	53.1	59.9
L_f(cal g^{-1})	29.5	33.3
L_f(J g^{-1})	165.3	139.3

57KAC; 53WIL/DOL; 67FRA/MIS

NYLON-6,10; solid; ribbon; (polyhexamethylenesebacamide); repeating unit: $C_{16}H_{30}N_2O_2$; average mol. wt. 9250.

specific heat: ribbon

temperature				
(K)	(°F)	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
273	32	0.327	0.327	1.368
293	68	0.373	0.373	1.561
313	104	0.420	0.420	1.757
333	140	0.486	0.486	2.033
353	176	0.512	0.512	2.142
373	212	0.518	0.518	2.167
393	248	0.531	0.531	2.222
413	284	0.561	0.561	2.347
433	320	0.592	0.592	2.477
453	356	0.588	0.588	2.460
473	392	0.686	0.686	2.870
493	428	1.95	1.95	8.159
513	464	0.737	0.737	3.084
523	482	0.639	0.639	2.674
533	500	0.627	0.627	2.623
543	518	0.632	0.632	2.644
553	536	0.639	0.639	2.674

melting point: 225°C (437°F); melting range 30°-40°C (54°-72°F)

heat of fusion: ribbon

L_f(Btu lb^{-1}) □ 47.3
L_f(cal g^{-1}) □ 26.3
L_f(J g^{-1}) □ 110.0

53WIL/DOL

PHENOL-FORMALDEHYDE RESIN, HARDENED (EDELKUNSTHARZ B); solid; empirical formula $C_{13}H_{12}O_2$.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 13598 ± 3.8 Btu lb^{-1}
q_v(gross) = 7554.3 ± 2.1 cal g^{-1}
q_v(gross) = 31607.2 ± 8.8 J g^{-1}

67FRA/MIS

PHENOL-FORMALDEHYDE RESIN, UNHARDENED; solid; empirical formula $C_{14}H_{14}O_3$.

gross heat of combustion: at 25°C (77°F)

$q_v(\text{gross}) = 12968 \pm 3.6$ Btu lb^{-1}
$q_v(\text{gross}) = 7204.2 \pm 2.0$ cal g^{-1}
$q_v(\text{gross}) = 30142.4 \pm 8.4$ J g^{-1}

67FRA/MIS

POLYACENAPHTHYLENE; solid; amorphous; repeating unit: $C_{12}H_8$; degree of polymerization ~600 units.

gross heat of combustion: at 25°C (77°F)

$q_v(\text{gross}) = 16898 \pm 3.6$ Btu lb^{-1}
$q_v(\text{gross}) = 9388.0 \pm 2.0$ cal g^{-1}
$q_v(\text{gross}) = 39279.4 \pm 8.4$ J g^{-1}

68JOS

POLYALLYLPHTHALATE; solid; empirical formula $C_{14}H_{14}O$.

gross heat of combustion: at 25°C (77°F)

$q_v(\text{gross}) = 11934 \pm 3.8$ Btu lb^{-1}
$q_v(\text{gross}) = 6629.8 \pm 2.1$ cal g^{-1}
$q_v(\text{gross}) = 27739.1 \pm 8.8$ J g^{-1}

67FRA/MIS

POLYBUTADIENE 41°F; solid; analysis: carbon, 88.47%; hydrogen, 11.160%; sulfur, 0.083%; oxygen, 0.12%; ash, 0.34%; phenyl-β-naphthylamine, 0.10%; repeating unit: C_4H_6; polymerization is carried out at 5°C (41°F).

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} $°\text{F}^{-1}$)	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
50	-370	0.08532	0.08532	0.3570
100	-280	0.15832	0.15832	0.6624
150	-190	0.22416	0.22416	0.9379
200	-100	0.359	0.359	1.50
250	- 10	0.433	0.433	1.81
300	80	0.471	0.471	1.97
330	134	0.4940	0.4940	2.067

53aFUR/McC

POLYBUTADIENE 122°F; solid; analysis: carbon, 88.66%; hydrogen, 11.180%; sulfur, 0.150%; oxygen, 0.145%; ash, 0.097%; phenyl-β-naphthylamine, 0.12%; repeating unit: C_4H_6; polymerization carried out at 50°C (132°F).

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
50	-370	0.08640	0.08640	0.3615
100	-280	0.15777	0.15777	0.6601
150	-190	0.22299	0.22299	0.9330
200	-100	0.3967	0.3967	1.66
250	- 10	0.4326	0.4326	1.81
300	80	0.4680	0.4680	1.958
330	134	0.4919	0.4919	2.058

53aFUR/McC

POLY-1-BUTENE; solid; isotactic; 34% crystallinity; repeating unit: C_4H_8; degree of polymerization ~800 units.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 19996.9 ± 0.9 Btu lb^{-1}
q_v(gross) = 11109.4 ± 0.5 cal g^{-1}
q_v(gross) = 46481.7 ± 2.1 J g^{-1}

68JOS

POLY-iso-BUTENE; (Sample 1) viscous liquid; mol. wt. ~4900; (Sample 2) amorphous solid, rubberlike; mol. wt. ~200000; 0.033% ash; (Sample 3) solid; Opanol B 100; repeating unit: C_4H_8.

gross heat of combustion: at 25°C (77°F)

Sample 1

q_v(gross) = 20123.6 ± 2.3 Btu lb^{-1}
q_v(gross) = 11179.8 ± 1.3 cal g^{-1}
q_v(gross) = 46776.3 ± 5.4 J g^{-1}

Sample 2

q_v(gross) = 20116.4 ± 3.6 Btu lb^{-1}
q_v(gross) = 11175.8 ± 2.0 cal g^{-1}
q_v(gross) = 46759.5 ± 8.3 J g^{-1}

Sample 3

q_v(gross) = 20122.4 ± 7.7 Btu lb^{-1}
q_v(gross) = 11179.1 ± 4.3 cal g^{-1}
q_v(gross) = 46773.4 ± 18.0 J g^{-1}

49PAR/MOS; 67FRA/MIS

POLY-1,1-DICHLOROETHYLENE (polyvinylidene chloride); solid; repeating unit: $C_2H_2Cl_2$; purity 99.9 mol %.

gross heat of combustion: at 25°C (77°F)

$q_V(\text{gross}) = 4527.2 \pm 3.8$ Btu lb^{-1}
$q_V(\text{gross}) = 2515.1 \pm 2.1$ cal g^{-1}
$q_V(\text{gross}) = 10523.2 \pm 8.8$ J g^{-1}

58SIN/STU

POLY-1,1-DIFLUOROETHYLENE (polyvinylidene fluoride); solid; repeating unit: $C_2H_2F_2$; particle size 100 mesh.

gross heat of combustion: at 25°C (77°F)

$q_V(\text{gross}) = 6352.4 \pm 0.7$ Btu lb^{-1}
$q_V(\text{gross}) = 3529.1 \pm 0.4$ cal g^{-1}
$q_V(\text{gross}) = 14765.8 \pm 1.7$ J g^{-1}

64GOO/LAC

POLY-2,6-DIMETHYLPHENYLENE ETHER; solid; repeating unit: C_8H_8O; 20% crystallinity; degree of polymerization ~300 units.

gross heat of combustion: at 25°C (77°F)

$q_V(\text{gross}) = 14892 \pm 2.5$ Btu lb^{-1}
$q_V(\text{gross}) = 8273.2 \pm 1.4$ cal g^{-1}
$q_V(\text{gross}) = 34615.1 \pm 5.9$ J g^{-1}

68JOS

POLY-4,4'-DIOXYDIPHENYL-2,2-PROPANE CARBONATE; solid; empirical formula $C_{16}H_{14}O_3$.

gross heat of combustion: at 25°C (77°F)

PKU T 22

$q_V(\text{gross}) = 13336 \pm 3.8$ Btu lb^{-1}
$q_V(\text{gross}) = 7408.7 \pm 2.1$ cal g^{-1}
$q_V(\text{gross}) = 30998.0 \pm 8.8$ J g^{-1}

Makrolon; solid.

$q_V(\text{gross}) = 13336 \pm 3.6$ Btu lb^{-1}
$q_V(\text{gross}) = 7408.7 \pm 2.0$ cal g^{-1}
$q_V(\text{gross}) = 30998.0 \pm 8.4$ J g^{-1}

Lexan; General Electric trade name; 20% crystallinity; degree of polymerization ~150 units.

$q_V(\text{gross}) = 13307 \pm 2.5$ Btu lb^{-1}
$q_V(\text{gross}) = 7392.9 \pm 1.4$ cal g^{-1}
$q_V(\text{gross}) = 30931.9 \pm 5.9$ J g^{-1}

68JOS; 67FRA/MIS

POLY-ε-ENANTHOLACTAM; solid; repeating unit: $C_7H_{13}NO$.

gross heat of combustion: at 20°C (68°F)

q_V(gross) = 14359 ± 9.9 Btu lb^{-1}
q_V(gross) = 7977.2 ± 5.5 cal g^{-1}
q_V(gross) = 33376.6 ± 23.0 J g^{-1}

57KAC

POLYETHYLENE; solid; NBS Standard Reference Material (SRM) 1475; linear polymer; wt.-ave. molecular weight, 52000; methyl group content, 0.15 methyl groups per 100 carbon atoms; ash content, 0.002%; 111 ppm of anti-oxidant [tetrakis-(methylene-3-(3', 5'-di-tert-butyl-4'-hydroxphenyl) propionate) methane] added to polymer by manufacturer; density at 23°C (73°F), 0.9784 g cm^{-3}; degree of crystallinity determined to be 72%; repeating unit: C_2H_4.

gross heat of combustion: at 25°C (77°F)

SRM 1475, crystallinity 72%

q_V(gross) = 19932.7 ± 3.8 Btu lb^{-1}
q_V(gross) = 11073.7 ± 2.1 cal g^{-1}
q_V(gross) = 46332.4 ± 8.8 J g^{-1}

SRM 1475 modified by recrystallization under high pressure; crystallinity 96%.

q_V(gross) = 19905.5 ± 3.6 Btu lb^{-1}
q_V(gross) = 11058.6 ± 2.0 cal g^{-1}
q_V(gross) = 46269.1 ± 8.1 J g^{-1}

specific heat: SRM 1475

temperature (K)	(°F)	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
10	-442	0.0029	0.0029	0.0123
100	-280	0.1632	0.1632	0.6829
200	-100	0.2839	0.2839	1.1877
250	- 10	0.3537	0.3537	1.4800
273.15	32	0.3936	0.3936	1.6468
298.15	77	0.4376	0.4376	1.8308
320	116	0.4790	0.4790	2.0040
360	188	0.5904	0.5904	2.4702

74SPL/JOH; 73CHA/BES

POLYETHYLENE; solid; (sample 1) high pressure; mol. wt. 18000-20000; crystallinity 50%; (sample 2) linear; Marlex; crystallinity 98%; (sample 3) low density; (sample 4) high density, Mirathen H; repeating unit: C_2H_4.

gross heat of combustion: at 25°C (77°F)

sample 1

q_V(gross) = 19968.5 ± 1.4 Btu lb^{-1}
q_V(gross) = 11093.6 ± 0.8 cal g^{-1}
q_V(gross) = 46415.6 ± 3.3 J g^{-1}

sample 2

q_V(gross) = 19945.6 ± 3.6 Btu lb^{-1}
q_V(gross) = 11080.9 ± 2.0 cal g^{-1}
q_V(gross) = 46362.5 ± 8.4 J g^{-1}

sample 3

q_V(gross) = 19876.9 ± 6.3 Btu lb^{-1}
q_V(gross) = 11042.7 ± 3.5 cal g^{-1}
q_V(gross) = 46202.7 ± 14.6 J g^{-1}

sample 4

q_V(gross) = 19985.2 ± 8.3 Btu lb^{-1}
q_V(gross) = 11102.9 ± 4.6 cal g^{-1}
q_V(gross) = 46485.5 ± 19.2 J g^{-1}

49PAR/MOS; 63PAR/MOS; 67FRA/MIS

POLY-α-METHYL STYRENE; solid; anionic; amorphous; samples with different degrees of polymerization, ~34000 units and ~13000 units gave the same heat of combustion; repeating unit: C_9H_{10}.

gross heat of combustion: at 25°C (77°F)

q_V(gross) = 18201.2 ± 5.0 Btu lb^{-1}
q_V(gross) = 10111.8 ± 2.8 cal g^{-1}
q_V(gross) = 42307.8 ± 11.7 J g^{-1}

68JOS

POLY(OXY-2-METHYL-1,4-CYCLOHEXYLENE); solid; Repeating unit $(C_7H_{12}O)_n$ was formed from endo-2-methyl-7-oxabicyclo [2.2.1] heptane by polymerization in CH_2Cl_2. Density was 0.823 g cm^{-3}, and material was a white powdery solid.

gross heat of combustion: temperature = 25°C (77°F), pressure was 30 atm oxygen, mean value was based on percentage recovery of CO_2.

q_V(gross) = 16030.69 ± 3.94 Btu lb^{-1}
q_V(gross) = 8905.94 ± 2.19 cal g^{-1}
q_V(gross) = 37262.45 ± 9.15 J g^{-1}

heat of polymerization: temperature = 25°C (77°F), $nC_7H_{12}O(liq) \rightarrow (C_7H_{12}O)_n$ (solid)

ΔH(polymerization) = -127.7 ± 14.2 Btu lb^{-1}
ΔH(polymerization) = - 70.95 ± 7.9 cal g^{-1}
ΔH(polymerization) = -296.9 ± 33.0 J g^{-1}

75AND/BAR

POLYPROPYLENE; solid; repeating unit: C_3H_6.

gross heat of combustion: at 25°C (77°F)

isotactic; 58% crystallinity

q_v(gross) = 19948.3 ± 4 Btu lb^{-1}
q_v(gross) = 11082.4 ± 2.2 cal g^{-1}
q_v(gross) = 46368.8 ± 9.2 J g^{-1}

degree of polymerization ~4000 units

q_v(gross) = 19944.9 ± 4 Btu lb^{-1}
q_v(gross) = 11080.5 ± 2.2 cal g^{-1}
q_v(gross) = 46360.8 ± 9.2 J g^{-1}

Polypropylene VK166, untangled

q_v(gross) = 19838 ± 9.2 Btu lb^{-1}
q_v(gross) = 11021.2 ± 5.1 cal g^{-1}
q_v(gross) = 46112.7 ± 21.3 J g^{-1}

63PAR/MOS; 67FRA/MIS

POLYSTYRENE; solid; repeating unit: C_8H_8.

gross heat of combustion: at 25°C (77°F)

isotactic, 40% crystallinity

q_v(gross) = 17838 ± 5.6 Btu lb^{-1}
q_v(gross) = 9909.9 ± 3.1 cal g^{-1}
q_v(gross) = 41463.0 ± 13.0 J g^{-1}

isotactic, amorphous

q_v(gross) = 17853 ± 4.3 Btu lb^{-1}
q_v(gross) = 9918.5 ± 2.4 Btu lb^{-1}
q_v(gross) = 41499.0 ± 10.0 J g^{-1}

atactic, amorphous

q_v(gross) = 17858 ± 2.5 Btu lb^{-1}
q_v(gross) = 9921.2 ± 1.4 cal g^{-1}
q_v(gross) = 41510.3 ± 5.9 J g^{-1}

polystyrol BW

q_v(gross) = 17860 ± 7.2 Btu lb^{-1}
q_v(gross) = 9922.4 ± 4.0 cal g^{-1}
q_v(gross) = 41515.3 ± 16.7 J g^{-1}

polystyrol P70

q_v(gross) = 17821 ± 5.4 Btu lb^{-1}
q_v(gross) = 9900.5 ± 3.0 cal g^{-1}
q_v(gross) = 41423.7 ± 12.6 J g^{-1}

67FRA/MIS; 68JOS

POLYUREA (POLYHARNSTOFF); solid; empirical formula $C_{15}H_{18}O_4N_4$; a polymer of adipic acid diamide plus (2,4-2,6)-toluene diisocyanate.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 10717 ± 3.1 Btu lb^{-1}
q_v(gross) = 5954.0 ± 1.7 cal g^{-1}
q_v(gross) = 24911.5 ± 7.1 J g^{-1}

67FRA/MIS

POLYVINYL CHLORIDE; solid; Repeating unit is $(\text{-CH}_2\text{CHCl-})_n$, it is a synthetic thermoplastic polymer. Purity is 99.7 mole %.

gross heat of combustion: temperature is 25°C (77°F), and value given is per monomer unit.

$q_v(\text{gross}) = 7874.7 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 4374.8 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 18304.3 \text{ J g}^{-1}$

58SIN/STU

PROPARGYL AZIDE POLYMER; solid; Polymer was formed when an alcohol-water solution of propargyl bromide and sodium azide was refluxed and the product $(C_3H_3N_3)_n$ appears to be primarily a 4-methylene-1,2,3-triazole polymer (the 5 methylene configuration is also possible). Analysis found C = 44.04, H = 4.07, N = 49.57, and O = 1.97 wt.% (oxygen is due to water that is occluded or chemically bound).

gross heat of combustion: assume values refer to room temperature; sample was dried under vacuum at 100°C; mean values were corrected for HNO_3 formation.

$q_v(\text{gross}) = 9454 \pm 22 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 5252 \pm 12 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 21974 \pm 50 \text{ J g}^{-1}$

73HOU/HUM

RESIN, ABS I; solid; copolymer of styrene-acrylonitrile = 76% and polybutadiene = 15%.

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
163	-166	0.184	0.184	0.770
217	- 69	0.240	0.240	1.004
277	39	0.311	0.311	1.301
298	77	0.338	0.338	1.414
328	131	0.373	0.373	1.561
380	225	0.492	0.492	2.059
430	315	0.518	0.518	2.167
477	399	0.541	0.541	2.264

specific heat change at glass transition temperature:

temperature (K)	(°F)	ΔC_p(Btu lb^{-1} °F^{-1})	ΔC_p(cal g^{-1} K^{-1})	ΔC_p(J g^{-1} K^{-1})
188	-121	0.014	0.014	0.059
377	217	0.069	0.069	0.289

70BAI

RILSAN; solid; (poly-11-aminodecanoic acid); empirical formula $C_{11}H_{21}ON$.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 15913 ± 4 Btu lb^{-1}
q_v(gross) = 8840.3 ± 2.2 cal g^{-1}
q_v(gross) = 36987.8 ± 8.4 J g^{-1}

67FRA/MIS

TEFLON; solid; (E.I. duPont de Nemours and Company trade name); (polytetrafluoroethylene); repeating unit: C_4F_4; density, 2.2 g cm^{-3}.

gross heat of combustion in oxygen: at 25°C (77°F); combustion products are gaseous carbon dioxide and carbon tetrafluoride.

q_v(gross) = 2154.1 ± 18 Btu lb^{-1}
q_v(gross) = 1196.7 ± 10.0 cal g^{-1}
q_v(gross) = 5007.0 ± 42 J g^{-1}

gross heat of combustion in fluorine: 25°C (77°F); combustion product is carbon tetrafluoride.

q_v(gross) = 4461.8 ± 1.3 Btu lb^{-1}
q_v(gross) = 2478.8 ± 0.7 cal g^{-1}
q_v(gross) = 10371.3 ± 3.1 J g^{-1}

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
50	-370	0.04821	0.04821	0.2017
100	-280	0.09218	0.09218	0.3857
150	-190	0.13380	0.13380	0.5598
200	-100	0.17706	0.17706	0.7408
250	- 10	0.21076	0.21076	0.8818
270	26	0.22768	0.22768	0.9526
280	44	0.24187	0.24187	1.012
310	98	0.24402	0.24402	1.021
330	134	0.24809	0.24809	1.038
360	188	0.25669	0.25669	1.074

transition temperatures:

293 K (20°C) (68°F)
303 K (30°C) (86°F)

heat of transition: for the temperature range 280-310 K.

L_f = 15.7 Btu lb^{-1}
L_f = 8.72 cal g^{-1}
L_f = 36.5 J g^{-1}

67DOM/ARM; 52FUR/McC

TROCKENLEIM (DRYING GLUE); solid; elementary analysis: carbon, 35.49%; hydrogen, 6.19%; oxygen, 30.91%; nitrogen, 27.41%; a urea-formaldehyde resin; empirical formula $C_3H_6O_2N_2$.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 6840.7 ± 3.6 Btu lb^{-1}
q_v(gross) = 3800.4 ± 2.0 cal g^{-1}
q_v(gross) = 15900.9 ± 8.4 J g^{-1}

67FRA/MIS

Polypeptides and Proteins

BOVINE CHYMOTRYPSINOGEN A; solid; Anhydrous material is a protein from beef pancreas made up of 245 amino acids with mol. wt. of 25646.

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
10	-442	0.00448	0.00448	0.01874
100	-280	0.1120	0.1120	0.4686
150	-190	0.1696	0.1696	0.7096
200	-100	0.2153	0.2153	0.9008
250	- 10	0.2617	0.2617	1.9050
298.15	77	0.3090	0.3090	1.2929
300	80	0.3109	0.3109	1.3008

69HUT/COL

CASEIN, MILK; solid; carbon, 53%; hydrogen, 7%; oxygen, 22.65%; nitrogen, 15.7%; sulfur, 0.8%; phosphorus, 0.85%.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 10210 ± 360 Btu lb^{-1}
q_v(gross) = 5670 ± 200 cal g^{-1}
q_v(gross) = 23700 ± 800 J g^{-1}

55MER/WAT

CHYMOTRYPSIN; nonaqueous; A proteolyic enzyme found in the intestine that catalyzes the hydrolysis of various proteins (especially casein) to form polypeptides and amino acids.

heat of denaturation: protein solution is 0.180 mass % in a 0.1 mol dm^{-3} glycine buffer with pH = 3.5.

ΔH denaturation □ 11.43 Btu lb^{-1}
ΔH denaturation □ 6.35 cal g^{-1}
ΔH denaturation □ 26.57 J g^{-1}

specific heat: the apparent molal specific heat of a protein solution of 0.180 mass % in a 0.1 mol dm^{-3} glycine buffer at pH □ 3.5; thermochemical calorie used.

temperature (K)	(°F)	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
298	77	0.31 ± 0.01	0.31 ± 0.01	1.30 ± 0.04
313	104	0.34 ± 0.01	0.34 ± 0.01	1.42 ± 0.04

75PRI/PLO

COLLAGEN; solid; fibrous protein that comprises the major portion of the white fiber in connective tissues of the animal body; chief amino acids present are proline, hydroxyproline, and glycine; converted to gelatine by boiling with water.

specific heat: 298 K (77°F)

moisture content (wt. %)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
0	0.3723	0.3723	1.5577
1.02	0.3490	0.3490	1.4602
1.96	0.3659	0.3659	1.5309
4.56	0.4014	0.4014	1.6795
6.49	0.4061	0.4061	1.6991
17.03	0.4280	0.4280	1.7908

55KAN

GELATINE; solid; a protein obtained from collagen by boiling skin, ligaments, tendons, bones, etc. with water; can absorb 5 to 10 times its weight of water.

gross heat of combustion: assume values refer to room temperature.

As received: ash content, 0.6%-0.8%; water content not determined.

q_v(gross) = 7920 Btu lb^{-1}
q_v(gross) = 4400 cal g^{-1}
q_v(gross) = 18410 J g^{-1}

Ash free and moisture free

q_v(gross) = 9270 ± 180 Btu lb^{-1}
q_v(gross) = 5150 ± 100 cal g^{-1}
q_v(gross) = 21550 ± 400 J g^{-1}

15ROT/WAL

GLIADIN; solid; also called prolomin; simple vegetable protein found in gluten; typical composition: carbon, 52.7%; hydrogen, 6.9%; oxygen, 21.7%; nitrogen, 17.7%; sulfur, 1.0%.

gross heat of combustion:

variation with thermal denaturation temperature.

denaturation temperature (°C)	(°F)	q_v(gross) Btu lb^{-1}	cal g^{-1}	J g^{-1}
30	86	10775	5986.3	25046.7
35	95	10640	5911.3	24732.9
50	122	10399	5777.2	24171.8
70	158	10457	5809.3	24306.1
110	230	10535	5852.8	24488.1

variation with concentration of aqueous alcohol used in extraction.

alcohol %	q_v(gross) Btu lb^{-1}	cal g^{-1}	J g^{-1}
40	10600	5891	24648
50	10560	5869	24556
60	10700	5942	24861
70	10850	6028	24221

66PON

GLUTEN; solid; mixture of proteins found in the seeds of cereal grains [wheat, corn (maize), etc.] which remains after washing the starch out of flour with water; amino acids of glutens are glutamic acid, leucine, proline, and arginine.

gross heat of combustion: variation with thermal denaturation temperature.

denaturation temperature (°C)	(°F)	q_v(gross) Btu lb^{-1}	cal g^{-1}	J g^{-1}
30	86	10436	5797.9	24258.4
35	95	10572	5873.2	24573.5
50	122	10168	5648.8	23634.6
70	158	10298	5721.1	23937.1
110	230	10403	5779.6	24181.8

66PON

GLUTENIN; solid; wheat protein soluble in dilute alkalies.

gross heat of combustion: variation with thermal denaturation temperature.

denaturation temperature (°C)	(°F)	q_v(gross) Btu lb^{-1}	cal g^{-1}	J g^{-1}
30	86	10278	5710.1	23891.1
35	95	10315	5730.3	23975.6
50	122	10050	5583.1	23359.7
70	158	10177	5654.0	23656.3
110	230	10260	5699.9	23848.4

66PON

INSULIN, BOVINE ZINC; solid; the anhydrous material from beef pancreas made up of 16 amino acids arranged in two chains connected by sulfur bridges, ($C_{508}H_{752}O_{150}N_{130}S_{12}Zn$). The ash content = 0.95%; zinc present (as ZnO) = 0.67%.

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
10	-442	0.00475	0.00475	0.01987
100	-280	0.1192	0.1192	0.4987
200	-100	0.2089	0.2089	0.8740
250	- 10	0.2541	0.2541	1.0632
298.15	77	0.2996	0.2996	1.2535
300	80	0.3014	0.3014	1.2611

69HUT/COL

PHENYLALANINE POLYMER; solid; repeating unit: C_9H_9NO.

gross heat of combustion: at 25°C (77°F)

benzene soluble	benzene insoluble
q_v(gross) = 13506 ± 11 Btu lb^{-1}	q_v(gross) = 13462 ± 12 Btu lb^{-1}
q_v(gross) = 7503.2 ± 6.0 cal g^{-1}	q_v(gross) = 7479.1 ± 6.9 cal g^{-1}
q_v(gross) = 31393.4 ± 25.1 J g^{-1}	q_v(gross) = 31292.6 ± 28.9 J g^{-1}

52BRE/TER

POLY-N-ETHYL-N-METHYL PROPIONAMIDE; solid; density, 1.44 g cm^{-3}; repeating unit: $C_6H_{13}NO$.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 14525 ± 1.8 Btu lb^{-1}
q_v(gross) = 8069.3 ± 1.0 cal g^{-1}
q_v(gross) = 33762.0 ± 4.2 J g^{-1}

59KOZ/SKU

SARCOSINE POLYMER; solid; repeating unit: C_3H_5NO.

gross heat of combustion: at 25°C (77°F)

q_v(gross) = 10128 ± 7.6 Btu lb^{-1}
q_v(gross) = 5626.4 ± 4.2 cal g^{-1}
q_v(gross) = 23540.9 ± 17.6 J g^{-1}

52BRE/TER

VITELLIN; solid; globulin protein from egg yolk; typical composition: water, 49.4%; protein, 16.3%; fat, 31.9%; carbohydrate, 0.7%; remainder includes small amounts of elements such as phosphorus, sulfur, iron, and calcium.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 10370 Btu lb^{-1}
q_v(gross) = 5760 cal g^{-1}
q_v(gross) = 24100 J g^{-1}

55MER/WAT

WOOL; solid; staple fibers obtained from the fleece of sheep (and also alpaca, vicuna, and certain goats); protein chains (keratin) bound together by disulfide cross linkages; chief amino acids: cysteine and cystine, 15%; glutamic acid, 16%; arginine, 10%; proline, 8%; leucine, 8%; sulfur content of wood sample, 3.5%.

gross heat of combustion: assume values refer to room temperature; dry basis, sulfur product aqueous H_2SO_4.

q_v(gross) = 9898 Btu lb^{-1}
q_v(gross) = 5499 cal g^{-1}
q_v(gross) = 23008 J g^{-1}

31PAS/KON

WOOL ACETATE; solid; salt formed from reaction of wool with acetic acid; 0.30% acetate.

gross heat of combustion: assume values refer to room temperature; sulfur product aqueous H_2SO_4.

$q_v(\text{gross}) = 9882$ Btu lb^{-1}
$q_v(\text{gross}) = 5490$ cal g^{-1}
$q_v(\text{gross})$ □ 22970 J g^{-1}

31PAS/KON

WOOL β-NAPHTHALENE SULFONATE; solid; salt formed from reaction of wool with β-naphthalenesulfonic acid; 19.9% β-naphthalenesulfonate.

gross heat of combustion: assume values refer to room temperature; sulfur product aqueous H_2SO_4.

$q_v(\text{gross}) = 9868$ Btu lb^{-1}
$q_v(\text{gross}) = 5482$ cal g^{-1}
$q_v(\text{gross})$ □ 22937 J g^{-1}

31PAS/KON

WOOL OXALATE; solid; salt formed from reaction of wool with oxalic acid; 2.22% oxalate.

gross heat of combustion: assume values refer to room temperature; sulfur product aqueous H_2SO_4.

$q_v(\text{gross}) = 9648$ Btu lb^{-1}
$q_v(\text{gross}) = 5360$ cal g^{-1}
$q_v(\text{gross}) = 22426$ J g^{-1}

31PAS/KON

WOOL PICRATE; solid; salt formed from reaction of wool with picric acid; 18.4% picrate.

gross heat of combustion: assume values refer to room temperature; sulfur product aqueous H_2SO_4.

$q_v(\text{gross}) = 9077$ Btu lb^{-1}
$q_v(\text{gross}) = 5043$ cal g^{-1}
$q_v(\text{gross})$ □ 21100 J g^{-1}

31PAS/KON

WOOL PROTEIN; solid; material is a keratin containing 14.3% cystine, 3.9% sulfur, and 16.85% nitrogen.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

$q_V(\text{gross}) = 10100 \pm 4.1$ Btu lb^{-1}
$q_V(\text{gross}) = 5609 \pm 2.3$ cal g^{-1}
$q_V(\text{gross}) = 23468 \pm 9.6$ J g^{-1}

64PAL/REI

WOOL SULFATE; solid; salt formed from reaction of wool with sulfuric acid, 2.21% sulfate.

gross heat of combustion: assume values refer to room temperature, sulfur product aqueous H_2SO_4.

$q_V(\text{gross}) = 9625$ Btu lb^{-1}
$q_V(\text{gross}) = 5347$ cal g^{-1}
$q_V(\text{gross}) = 22372$ J g^{-1}

31PAS/KON

WOOL p-TOLUENESULFONATE; solid; salt formed from reaction of wool with p-toluene-sulfonic acid; 6.6% p-toluenesulfonate.

gross heat of combustion: assume values refer to room temperature; sulfur product aqueous H_2SO_4.

$q_V(\text{gross}) = 9824$ Btu lb^{-1}
$q_V(\text{gross}) = 5458$ cal g^{-1}
$q_V(\text{gross}) = 22836$ J g^{-1}

31PAS/KON

Refuse

REFUSE; solid; Samples are dry shredded garbage (essentially free of glass and metals). The refuse material contained significant amounts of reduced carbonaceous materials such as plastics, waxes, and oils.

gross heat of combustion: value is average of two trials, assume values refer to room temperature.

sample A

$q_V(\text{gross}) = 7959$ Btu lb^{-1}
$q_V(\text{gross}) = 4422$ cal g^{-1}
$q_V(\text{gross}) = 18500$ J g^{-1}

sample B

$q_V(\text{gross}) = 8540$ Btu lb^{-1}
$q_V(\text{gross}) = 4744$ cal g^{-1}
$q_V(\text{gross}) = 19850$ J g^{-1}

sample C

$q_V(\text{gross}) = 8621$ Btu lb^{-1}
$q_V(\text{gross}) = 4790$ cal g^{-1}
$q_V(\text{gross}) = 20040$ J g^{-1}

sample D

$q_V(\text{gross}) = 8626$ Btu lb^{-1}
$q_V(\text{gross}) = 4792$ cal g^{-1}
$q_V(\text{gross}) = 20050$ J g^{-1}

77JEN/EAT

REFUSE-DERIVED FUEL; solid; Refuse-derived fuel-3 (RDF-3) was obtained from the National Center for Resource Recovery (NCRR), Washington, D.C. Sample was air-dried and processed to 0.5 mm particle size for laboratory test analysis.

gross heat of combustion: assume values refer to room temperature; values are on a moisture-free, ash-free basis.

Sample 1, tested during June and July 1978. Residual moisture, 5.031 wt. %; ash content, 24.18 wt. %; sulfur content, 0.13 wt. %.

$q_V(\text{gross}) = 9796$ Btu lb^{-1}
$q_V(\text{gross}) = 5446$ cal g^{-1}
$q_V(\text{gross}) = 22785$ J g^{-1}

Sample 2, tested during Dec. 1978 and Jan. 1979. Residual moisture, 6.090 wt. %; ash content, 14.62 wt. %; sulfur content, 0.14 wt. %.

$q_V(\text{gross}) = 9253$ Btu lb^{-1}
$q_V(\text{gross}) = 5144$ cal g^{-1}
$q_V(\text{gross}) = 21522$ J g^{-1}

Sample 3, tested during 1979. Residual moisture, 5.265 wt. %; ash content, 11.80 wt. %; sulfur content, 0.095 wt. %.

$q_V(\text{gross}) = 8062$ Btu $^{-1}$
$q_V(\text{gross}) = 4482$ cal g^{-1}
$q_V(\text{gross}) = 18752$ J g^{-1}

81KIR/COL

REFUSE-DERIVED FUEL; solid; Refuse-derived fuel-3 (RDF-3) was obtained from Americology, Milwaukee, Wis. Sample was air-dried and processed to 0.5 mm particle size for laboratory test analysis.

gross heat of combustion: assume values refer to room temperature; values are on a moisture-free, ash-free basis.

Sample 1, residual moisture, 4.796 wt. %; ash content, 22.52 wt. %; sulfur content, 0.48 wt. %.

q_V(gross) = 9438 Btu lb^{-1}
q_V(gross) = 5247 cal g^{-1}
q_V(gross) = 21953 J g^{-1}

Sample 2, residual moisture, 3.006 wt. %; ash content, 29.65 wt. %; sulfur content, 0.24 wt. %.

q_V(gross) = 9392 Btu lb^{-1}
q_V(gross) = 5221 cal g^{-1}
q_V(gross) = 21846 J g^{-1}

Sample 3, tested during 1979. Residual moisture, 5.265 wt. %; ash content, 11.80 wt. %; sulfur content, 0.095 wt. %.

q_V(gross) = 9525 Btu^{-1}
q_V(gross) = 5295 cal g^{-1}
q_V(gross) = 22155 J g^{-1}

81KIR/COL

REFUSE-DERIVED FUEL; solid; Refuse-derived fuel-3 (RDF-3) was obtained from the Baltimore County Resource Recovery Facility, Cockeysville, Md., operated by Teledyne National. Sample was air-dried and processed to 0.5 mm particle size for laboratory test analysis. Residual moisture, 5.065 wt. %; ash content, 15.87 wt. %; sulfur content, 0.14 wt. %.

gross heat of combustion: assume values refer to room temperature; values are on a moisture-free, ash-free basis.

q_V(gross) = 10553 Btu lb^{-1}
q_V(gross) = 5867 cal g^{-1}
q_V(gross) = 24546 J g^{-1}

81KIR/COL

REFUSE-DERIVED FUEL; solid; A sample of ECO FUEL-II RDF was obtained from Combustion Equipment Associates, Bridgeport, Conn. and has a particle size of about 0.42 mm (-40 mesh). Residual moisture, 1.627 wt. %; ash content, 13.71 wt. %; sulfur content, 0.46 wt. %.

gross heat of combustion: assume values refer to room temperature; values are on a moisture-free, ash-free basis.

q_V(gross) = 9451 Btu lb^{-1}
q_V(gross) = 5254 cal g^{-1}
q_V(gross) = 21983 J g^{-1}

81KIR/COL

REFUSE-DERIVED FUEL; solid; A synthetic refuse-derived fuel (RDF) has been developed at the National Bureau of Standards (NBS) and is designated as a standard reference material (SRM 1657). The composition of the synthetic RDF is approximately 80 mass % microcrystalline cellulose, 15 mass % silica, and 5 mass % alumina. All components have a nominal particle size of 50 micrometers. Residual moisture content, 3.7 mass %; ash content, 20.34 ± 0.54 mass %, dry basis.

gross heat of combustion: values refer to 25°C (77°F).

q_V(gross) = 5963 Btu lb^{-1} (dry-basis)
q_V(gross) = 3315 cal g^{-1} (dry-basis)
q_V(gross) = 13870 J g^{-1} (dry-basis)

q_V(gross) = 7481 Btu lb^{-1} (dry, ash-free)
q_V(gross) = 4159 cal g^{-1}(dry, ash-free)
q_V(gross) = 17400 J g^{-1}(dry, ash-free)

85COL

REFUSE, MUNICIPAL; solid; waste from the city of St. Louis; particle size of 1.5 in. and less, magnetic metal removed; (batch 1) from 210 samples collected April 1972 through February 1973, unclassified material, with only magnetic metal removed: moisture, 9.3%-50.0%; sulfur, 0.01%-0.40%; chlorine, 0.13%-0.95%; ash, 12.1%-52.2%; (batch 2) from 99 samples collected November 1973 through January 1974, classified material; heavy fraction of waste removed by air-density separation; light fraction only: moisture, 11.1%-66.3%; sulfur, 0.05%-0.28%; chlorine, 0.14%-0.94%; ash, 7.6%-21.4%.

gross heat of combustion: assume values refer to room temperature.

batch 1

minimum q_V(gross) = 3029 Btu lb^{-1}
minimum q_V(gross) = 1683 cal g^{-1}
minimum q_V(gross) = 7041 J g^{-1}

maximum q_V(gross) = 7430 Btu lb^{-1}
maximum q_V(gross) = 4128 cal g^{-1}
maximum q_V(gross) = 17270 J g^{-1}

average q_V(gross) = 4675 Btu lb^{-1}
average q_V(gross) = 2597 cal g^{-1}
average q_V(gross) = 10867 J g^{-1}

batch 2

minimum q_V(gross) = 2295 Btu lb^{-1}
minimum q_V(gross) = 1275 cal g^{-1}
minimum q_V(gross) = 5333 J g^{-1}

maximum q_V(gross) = 7598 Btu lb^{-1}
maximum q_V(gross) = 4221 cal g^{-1}
maximum q_V(gross) = 17661 J g^{-1}

average q_V(gross) = 5020 Btu lb^{-1}
average q_V(gross) = 2789 cal g^{-1}
average q_V(gross) = 11669 J g^{-1}

74WIS/SUT

REFUSE, MUNICIPAL; solid; waste from an English town; (sample 1) (on dry basis): paper, 29.6%; rags, 5.3%; vegetable matter, 5.1%; animal matter, 1.3%; wood, etc., 3.5%; coal, coke, cinders, 16.5%; metal, 4.9%; glass, pottery, and other non-combustible matter, 23.7%; fines, passing 1/4 in. × 1/4 in. square mesh, 10.1%; moisture, 34.0%; (sample 2) (on dry basis): paper, 4.8%; rags, 0.3%; vegetable matter, 1.0%; animal matter, 0.7%; wood, etc., 0.8%; coal, coke cinders, 36.1%; metal, 0.9%; glass, pottery, and other non-combustible material, 10.0%; fines, passing 1/4 in. × 1/4 in. square mesh, 45.4%; moisture, 17.2%.

gross heat of combustion: assume values refer to room temperature.

sample 1 (dry basis)	sample 2 (dry basis)
$q_V(\text{gross}) = 5598$ Btu lb^{-1}	$q_V(\text{gross}) = 7308$ Btu lb^{-1}
$q_V(\text{gross}) = 3110$ cal g^{-1}	$q_V(\text{gross}) = 4060$ cal g^{-1}
$q_V(\text{gross}) = 13012$ J g^{-1}	$q_V(\text{gross}) = 16987$ J g^{-1}

55SPI

Rubber Materials

DISCARDED AUTOMOBILES TIRES; solid; The destructive distillation of tires resulted in a solid residue, an organic liquid, and a combustible gas of undetermined heating value (the process produced a mass loss of 65%). There are four types of rubber used in tires: natural, styrene-butadiene, polyisoprene, and polybutadiene. A typical compounding formula for passenger tire treads made out of natural rubber: smoked sheet (57.6%), reogen (1.2%), stearic acid (1.4%), zinc oxide (2%), agerite resin D (0.9%), agerite HP (0.3%), antozite 675 (2.3%), microcrystalline wax (0.6%), philrich 5 (2.9%), HAF (28.8%), sulfur (1.4%), amax No. 1 (0.3%), and redax (0.3%). Gross heats of combustion were determined for the solid residue and organic liquid.

gross heat of combustion:

solid residue	organic liquid
q_v(gross) = 17000 Btu lb^{-1}	q_v(gross) = 13000 Btu lb^{-1}
q_v(gross) = 9600 cal g^{-1}	q_v(gross) = 7200 cal g^{-1}
q_v(gross) = 40000 J g^{-1}	q_v(gross) = 30000 J g^{-1}

74COL/DOW

GR-S RUBBER; solid; composed of 1-3 butadiene and 25 wt. % styrene. Analysis of material gave the following in percent by weight: carbon = 88.954, hydrogen = 10.2607, ash = 0.37, soap as sodium oleate = 0.42, fatty acid as oleic acid = 0.92, modifier = 0.44, phenyl-beta-naphthylamine = 0.50, and amount soluble in ethanol-toluene azeotrope = 5.6.

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
5	-450.4	0.0010	0.0010	0.004
10	-441.4	0.0067	0.0067	0.028
50	-369.4	0.081	0.081	0.338
100	-279.4	0.146	0.146	0.612
200	-99.4	0.268	0.268	1.12
300	80.6	0.454	0.454	1.90

44RAN/FER

PURIFIED NATURAL RUBBER HYDROCARBON; solid; prepared by digestion of latex with steam at 190°C (374°F) and extraction of resins and products of hydrolysis with alcohol and water. Nitrogen content was about 0.03%; ash content average 0.12%; benzene-insoluble constituents averaged 0.1%-0.3%.

specific heat:

temperature (K)	(°F)	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
15	-432	0.017	0.017	0.073
20	-423	0.028	0.028	0.117
50	-369	0.084	0.084	0.352
100	-279	0.154	0.154	0.646
200	- 99	0.344	0.344	1.44
300	80	0.452	0.452	1.89

heat of fusion: at 110°C (51.8°F).

$L_f = 7.18$ Btu lb^{-1}
$L_f = 3.99$ cal g^{-1}
$L_f = 16.7$ J g^{-1}

35BEK/MAT

RUBBER; solid; (sample 1): latex, digested with water at 190°C (374°F), extracted with water and ethanol; soluble in ether; 0.02% ash; (sample 2): latex, trypsin treated; 75% ether soluble, 25% ether insoluble.

gross heat of combustion: 30°C (86°F)

sample 1, 0.02% ash

q_v(gross) = 19465 Btu lb^{-1}
q_v(gross) = 10814 cal g^{-1}
q_v(gross) = 45247 J g^{-1}

sample 2, 0.4% ash

q_v(gross) = 19355 Btu lb^{-1}
q_v(gross) = 10753 cal g^{-1}
q_v(gross) = 44991 J g^{-1}

sample 2, 0.15% ash

q_v(gross) = 19411 Btu lb^{-1}
q_v(gross) = 10784 cal g^{-1}
q_v(gross) = 45120 J g^{-1}

sample 2, ether soluble fraction, 0.1% ash

q_v(gross) = 19444 Btu lb^{-1}
q_v(gross) = 10802 cal g^{-1}
q_v(gross) = 45196 J g^{-1}

sample 2, ether insoluble fraction, 0.7% ash

q_v(gross) = 19343 Btu lb^{-1}
q_v(gross) = 10746 cal g^{-1}
q_v(gross) = 44961 J g^{-1}

sample 2, ether insoluble fraction, 1.8% ash

q_v(gross) = 19129 Btu lb^{-1}
q_v(gross) = 10627 cal g^{-1}
q_v(gross) = 44464 J g^{-1}

34JES/CUM

RUBBER-SULFUR COMPOUNDS; solid; repeating unit: $[(C_5H_8)_xS_y]$; x varies between 1 and 4; y varies between 0 and 3; maximum sulfur content ~32%.

gross heat of combustion: at 30°C (86°F), sulfur as gaseous SO_2.

$q_v(\text{gross}) = 10791 - 9041\ m\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 45150 - 37828\ m\ \text{J g}^{-1}$

m is grams of sulfur per gram of compound

34JES/CUM

TIRE; solid; typical compounding formulae for passenger tire treads.

	Natural rubber %	SBR cis-polybutadiene* %
Smoked sheet	57.6	-
SBR 1712	-	46.8
cis-Polybutadiene	-	11.3
Reogen	1.2	-
K-Stay G	-	2.3
Stearic acid	1.4	0.9
Zinc oxide	2	1.4
Agerite resin D	0.9	0.7
Agerite HP	0.3	0.2
Antozite 67S	2.3	1.8
Microcrystalline wax	0.6	0.5
Philrich 5	2.9	3.2
HAF	28.8	-
ISAF	-	29.5
Sulfur	1.4	0.8
Amax No. 1	0.3	-
Amax	-	0.7
Redax	0.3	-

*SBR is styrene-butadiene rubber

gross heat of decomposition: at 375°C (707°F) the mean value is for random samples of black-sidewall tire tread; products are a liquid distillate with a heat of combustion $q_v = 40000\ \text{J g}^{-1}$ ($10000\ \text{cal g}^{-1}$) ($18000\ \text{Btu lb}^{-1}$) and a combustible gas.

$q_v(\text{gross}) = 1260\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 700\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 3000\ \text{J g}^{-1}$

gross heat of combustion: value for the tire residue remaining after heating to 1000°C (1832°F).

$q_v(\text{gross}) = 14000\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 7800\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 32640\ \text{J g}^{-1}$

74COL/DOW

Vegetable Oils

BARLEY OIL; liquid; oil from barley, *Hordeum vulgare*; obtained by ether extraction.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 16330 Btu lb^{-1}
q_v(gross) = 9070 cal g^{-1}
q_v(gross) = 37950 J g^{-1}

55MER/WAT

CASTOR OIL; liquid; The vegetable oil has a chemical composition of up to 3 fatty acids linked to a glycerine molecule with ester linkages; the fatty acid composition in percent by weight is palmitic = 1.09, stearic = 3.10, oleic = 4.85, linoleic = 1.27, and ricinoleic = 89.60. The acid value (number of mg of KOH needed to neutralize free fatty acids in 1 g sample) = 0.21, the phosphorus = 3.0 ppm, peroxide value (milliequivalents of peroxide per 1000 g sample that oxidize KI during test conditions) = 9.6, water and sediment (% by volume) = trace, carbon residue (% by weight) = 0.22, ash (% by weight) = 0.01, and sulfur (% by weight) = 0.01. Density = 0.9537 kg/L.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 16036 Btu lb^{-1}
q_v(gross) = 8909 cal g^{-1}
q_v(gross) = 37274 J g^{-1}

82GOE/SCH

CASTOR OIL; liquid; oil from seeds of the castor bean, *Ricinus communis*; chief constituent: glyceride of ricinoleic acid (12-hydroxyoleic acid). Saponification number 175-183. Iodine number 83 after heating at 100°C (212°F) for 3 to 6 hours at 2-3 mm pressure; density is 0.945-0.965 g cm^{-3} at 25°C (77°F).

specific heat: 298-548 K (77°-527°F)

C_p(Btu lb^{-1} °F^{-1}) = $0.41281 + 1.2259 \times 10^{-3}\,T - 3.4892 \times 10^{-6}\,T^2 + 3.8820 \times 10^{-9}\,T^3$
C_p(cal g^{-1} K^{-1}) = $-1.265 + 0.01241\,T - 2.8650 \times 10^{-5}\,T^2 + 2.264 \times 10^{-8}\,T^3$
C_p(J g^{-1} K^{-1}) = $-5.292 + 0.05192\,T - 1.1987 \times 10^{-4}\,T^2 + 9.474 \times 10^{-8}\,T^3$

46CLA/WAL

COCONUT OIL; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 255. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 10.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	15.21	8.45	35.35
0	32	37.30	20.72	86.69
25	77	89.62	49.79	208.32
50	122	124.97	69.43	290.50
55	131	129.22	71.79	300.37

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 55.1 Btu lb^{-1}
L_f = 30.6 cal g^{-1}
L_f = 128.0 J g^{-1}

55RIE

COCONUT OIL; liquid; extracted from coconut meat, *Cocos nucifera*; mixture of glycerides of lauric (~48%) and myristic (~17.5%) acids; remainder made up of glycerides of capyrlic, capric, palmitic, stearic, oleic, and linoleic acids. Saponification number 253-262.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 16330 Btu lb^{-1}
q_v(gross) = 9070 cal g^{-1}
q_v(gross) = 37950 J g^{-1}

55MER/WAT

CORN OIL; liquid; The vegetable oil has a chemical composition of up to 3 fatty acids linked to a glycerine molecule with ester linkages; the fatty acid composition in percent by weight is palmitic = 11.67, stearic = 1.85, oleic = 25.16, linoleic = 60.60, linolenic = 0.48, and arachidic = 0.24. The acid value (number of mg of KOH needed to neutralize free fatty acids in 1 g sample) = 0.11, the phosphorus = 7.0 ppm, peroxide value (milliequivalents of peroxide per 1000 g sample that oxidize KI during test conditions) = 18.4, water and sediment (% by volume) = trace, carbon residue (% by weight) = 0.24, ash (% by weight) = 0.01, and sulfur (% by weight) = 0.01. Density = 0.9095 kg/L.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 16993\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 9441\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 39500\ \text{J g}^{-1}$

82GOE/SCH

CORN OIL (MAIZE); liquid; extracted from corn (maize), *Zea mays*; typical analysis: triglycerides, 98.6%; unsaponifiable, 1.4%; sitosteral, 1%; fatty acid composition: palmitic, 2%; stearic, 3.5%; oleic, 46.3%; linoleic, 42.0%; Iodine number 117-130.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 16700\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 9280\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 38830\ \text{J g}^{-1}$

55MER/WAT

COTTONSEED OIL; liquid; The vegetable oil has a chemical composition of up to 3 fatty acids linked to a glycerine molecule with ester linkages; the fatty acid composition in percent by weight is palmitic = 28.33, stearic = 0.89, oleic = 13.27, and linoleic = 57.51. The acid value (number of mg of KOH needed to neutralize free fatty acids in 1 g sample) = 0.07, the phosphorus = 8.0 ppm, peroxide value (milliequivalents of peroxide per 1000 g sample that oxidize KI during test conditions) = 64.8, water and sediment (% by volume) = 0.04, carbon residue (% by weight) = 0.24, ash (% by weight) = 0.01, and sulfur (% by weight) = 0.01. Density = 0.9148 kg/L.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 16980\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 9433\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 39468\ \text{J g}^{-1}$

82GOE/SCH

COTTONSEED OIL, HYDROGENATED; liquid; yellow oil from various *Gossipyium* species; chief constituents are glycerides of palmitic (~21%); oleic (~33%); stearic (~2%); and linoleic (~44%) acids; density, 0.91-0.92 g cm^{-3}; before measurement, oil was heated at 100°C (212°F) for 3 to 6 hours at 2-3 mm of Hg to remove moisture. Iodine number 6.5.

specific heat: 353-543 K (176°-518°F)

C_p(Btu lb^{-1} $°F^{-1}$) $= 0.4962 + 8.859 \times 10^{-5}\,T + 3.8265 \times 10^{-7}\,T^2$
C_p(cal g^{-1} K^{-1}) $= 0.5363 - 4.7376 \times 10^{-4}\,T + 1.2398 \times 10^{-6}\,T^2$
C_p(J g^{-1} K^{-1}) $= 2.2439 - 1.9822 \times 10^{-3}\,T + 5.1875 \times 10^{-6}\,T^2$

46CLA/WAL

COTTONSEED OIL, REFINED; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 195. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 107.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	23.74	13.19	55.19
0	32	60.16	33.42	139.83
25	77	86.62	48.12	201.33
50	122	107.86	59.92	250.71
55	131	112.16	62.31	260.71

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

$L_f = 30.2$ Btu lb^{-1}
$L_f = 16.8$ cal g^{-1}
$L_f = 70.3$ J g^{-1}

55RIE

CRAMBE OIL; liquid; The vegetable oil has a chemical composition of up to 3 fatty acids linked to a glycerine molecule with ester linkages; the fatty acid composition in percent by weight is palmitic = 2.07, stearic = 0.70, oleic = 18.86, linoleic = 9.00, linolenic = 6.85, arachidic = 2.09, behenic = 0.80, lignoceric = 1.12, and erucic = 58.51. The acid value (number of mg of KOH needed to neutralize free fatty acids in 1 g sample) = 0.36, the phosphorus = 12.0 ppm, peroxide value (milliequivalents of peroxide per 1000 g sample that oxidize KI during test conditions) = 26.5, water and sediment (% by volume) = 0.2, carbon residue (% by weight) = 0.23, ash (% by weight) = 0.05, and sulfur (% by weight) = 0.01. Density = 0.9044 kg/L.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 17416 Btu lb^{-1}
q_V(gross) = 9675 cal g^{-1}
q_V(gross) = 40482 J g^{-1}

82GOE/SCH

GROUND NUT SEED OIL; liquid; Material was extracted from industrially stored oil seeds and the acid value was 10.1 mg KOH/g. Specific gravity, (15/15°C) = 0.9210. Fatty acids found in the oil: lauric (0.15%), linoleic (37.00%), palmitic (17.40%), palmitoleic (0.60%), stearic (2.30%), oleic (39.00%), linolenic (1.38%), eicosenoic (2.62%), and erucic (0.55%).

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 17118 Btu lb^{-1}
q_V(gross) = 9510 cal g^{-1}
q_V(gross) = 39790 J g^{-1}

75KOM/DAN

HIGH OLEIC SAFFLOWER OIL; liquid; The vegetable oil is a genetic variant of normal safflower oil and has a chemical composition of up to 3 fatty acids linked to a glycerine molecule with ester linkages; the fatty acid composition in percent by weight is palmitic = 5.46, stearic = 1.75, oleic = 79.36, linoleic = 12.86, arachidic = 0.23, and myristic = 0.34. The acid value (number of mg of KOH needed to neutralize free fatty acids in 1 g sample) = 0.26, the phosphorus = 0.42 ppm, peroxide value (milliequivalents of peroxide per 1000 g sample that oxidize KI during test conditions) = 13.6, water and sediment (% by volume) = trace, carbon residue (% by weight) = 0.24, ash (% by weight) = 0.001, and sulfur (% by weight) = 0.02. Density = 0.9021 kg/L.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 17000 Btu lb^{-1}
q_V(gross) = 9445 cal g^{-1}
q_V(gross) = 39516 J g^{-1}

82GOE/SCH

LINSEED OIL; liquid; Material was extracted from industrially stored oil seeds and the acid value was 3.81 mg KOH/g. Density (15°C) = 0.929 g cm^{-3}. Fatty acids found in the oil: palmitic (8.77%), stearic (5.67%), oleic (21.98%), linoleic (12.26%), and linolenic (51.32%).

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 17073 Btu lb^{-1}
q_V(gross) = 9485 cal g^{-1}
q_V(gross) = 39685 J g^{-1}

75KOM/DAN

LINSEED OIL; liquid; The vegetable oil has a chemical composition of up to 3 fatty acids linked to a glycerine molecule with ester linkages; the fatty acid composition in percent by weight is palmitic = 4.92, stearic = 2.41, oleic = 19.70, linoleic = 18.03, and linolenic = 54.94. The acid value (number of mg of KOH needed to neutralize free fatty acids in 1 g sample) = 0.20, the phosphorus = 6.0 ppm, peroxide value (milliequivalents of peroxide per 1000 g sample that oxidize KI during test conditions) = 33.7, water and sediment (% by volume) = trace, carbon residue (% by weight) = 0.22, ash (% by weight) = 0.01, and sulfur (% by weight) = 0.01. Density = 0.9236 kg/L.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 16910 Btu lb^{-1}
q_V(gross) = 9395 cal g^{-1}
q_V(gross) = 39307 J g^{-1}

82GOE/SCH

LINSEED OIL; liquid; (flaxseed oil); obtained from dried seeds of flax, *Linum usitatissiumum*; chief constituents are glycerides of linoleic (~61.5%), linolenic (~25.0%), palmitic (~5%), oleic (~5%), and stearic (~3.5%) acids; iodine number 172.1; density, 0.930-0.938 g cm^{-3}.

specific heat: sample was heated at 100°C (212°F) for 3 to 6 hours under a pressure of 2-3 mm of Hg to remove moisture; equations valid 30°-270°C (86°-518°F).

$C_p(\text{Btu lb}^{-1}\ {}^{\circ}\text{F}^{-1}) = 0.41604 + 6.9526 \times 10^{-4}\,T - 1.6518 \times 10^{-6}\,T^2 + 2.1420 \times 10^{-9}\,T^3$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = -0.4606 + 6.4288 \times 10^{-3}\,T - 1.4922 \times 10^{-5}\,T^2 + 1.2492 \times 10^{-8}\,T^3$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = -1.9272 + 2.6898 \times 10^{-2}\,T - 6.2434 \times 10^{-5}\,T^2 + 5.2267 \times 10^{-8}\,T^3$

46CLA/WAL

LINSEED OIL, UNREFINED; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 190. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 176.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature (°C)	temperature (°F)	H°(t)-H°(-50°C) Btu lb^{-1}	H°(t)-H°(-50°C) cal g^{-1}	H°(t)-H°(-50°C) J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	18.58	10.32	43.18
0	32	67.01	37.23	155.77
25	77	87.71	48.73	203.89
50	122	108.41	60.23	252.00
55	131	112.61	62.56	261.75

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

$L_f = 32.8$ Btu lb^{-1}
$L_f = 18.2$ cal g^{-1}
$L_f = 76.1$ J g^{-1}

55RIE

OAT OIL; liquid; obtained from oats, *Avena sativa*; obtained by ether extraction.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 16070 Btu lb^{-1}
q_v(gross) = 8930 cal g^{-1}
q_v(gross) = 37365 J g^{-1}

55MER/WAT

OLIVE OIL; liquid; mixture of glycerides of several fatty acids; chiefly glycerides of oleic acid, with lesser amounts of palmitic, stearic, and linoleic acids. Saponification number 185-196.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 17050 Btu lb^{-1}
q_v(gross) = 9470 cal g^{-1}
q_v(gross) = 39620 J g^{-1}

55MER/WAT

OLIVE OIL, ITALIAN; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 194. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 96.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	17.10	9.50	39.75
0	32	62.08	34.49	144.31
25	77	91.51	50.84	212.71
50	122	112.73	62.63	262.04
55	131	117.02	65.01	272.00

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 36.5 Btu lb^{-1}
L_f = 20.3 cal g^{-1}
L_f = 84.9 J g^{-1}

55RIE

PALM OIL, HARDENED; solid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 199. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 60.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	16.24	9.02	37.74
0	32	36.99	20.55	85.98
25	77	73.98	41.10	171.96
50	122	126.58	70.32	294.22
55	131	131.02	72.79	304.55

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 57.2 Btu lb^{-1}
L_f = 31.8 cal g^{-1}
L_f = 133.1 J g^{-1}

55RIE

PALM OIL, UNREFINED; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 200. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 55.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	16.25	9.03	37.78
0	32	38.75	21.53	90.08
25	77	89.68	49.82	208.45
50	122	118.71	65.95	275.93
55	131	123.07	68.37	286.06

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 46.4 Btu lb^{-1}
L_f = 25.8 cal g^{-1}
L_f = 107.9 J g^{-1}

55RIE

PALM-KERNEL OIL; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 242. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 16.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	15.57	8.65	36.19
0	32	40.14	22.30	93.30
25	77	94.14	52.30	218.82
50	122	124.97	69.43	290.50
55	131	129.38	71.88	300.75

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 57.6 Btu lb^{-1}
L_f = 32.0 cal g^{-1}
L_f = 133.9 J g^{-1}

55RIE

PEANUT OIL; liquid; The vegetable oil has a chemical composition of up to 3 fatty acids linked to a glycerine molecule with ester linkages; the fatty acid composition in percent by weight is palmitic = 11.38, stearic = 2.39, oleic = 48.28, linoleic = 31.95, linolenic = 0.93, arachidic = 1.32, behenic = 2.52, and lignoceric = 1.23. The acid value (number of mg of KOH needed to neutralize free fatty acids in 1 g sample) = 0.20, the phosphorus = 9.0 ppm, peroxide value (milliequivalents of peroxide per 1000 g sample that oxidize KI during test conditions) = 82.7, water and sediment (% by volume) = trace, carbon residue (% by weight) = 0.24, ash (% by weight) = 0.005, and sulfur (% by weight) = 0.01. Density = 0.9026 kg/L.

gross heat of combustion: assume values refer to room temperature.

$q_V(\text{gross}) = 17115\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 9508\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 39782\ \text{J g}^{-1}$

82GOE/SCH

PEANUT OIL, UNREFINED; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 192. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 92.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature (°C)	(°F)	H°(t)-H°(-50°C) Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	16.85	9.36	39.16
0	32	66.74	37.08	155.14
25	77	90.38	50.21	210.08
50	122	112.12	62.29	260.62
55	131	116.53	64.74	270.87

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

$L_f = 34.2\ \text{Btu lb}^{-1}$
$L_f = 19.0\ \text{cal g}^{-1}$
$L_f = 79.5\ \text{J g}^{-1}$

55RIE

PERILLA OIL; liquid; obtained from seeds of ***Perilla ocimoides***; chief constituents are glycerides of linoleic (~39%) and linolenic (~46%) acids, with small amounts of palmitic (~8%) and oleic (8%) acids; density, 0.93-0.94 g cm^{-3}; before measurement, oil was heated at 100°C (212°F) for 3 to 6 hours at 2-3 mm of Hg to remove moisture. Iodine number 186.2.

specific heat: 279-543 K (43°-518°F)

$$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.5350 + 1.499 \times 10^{-4}\ T + 3.086 \times 10^{-7}\ T^2$$
$$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.4082 - 2.410 \times 10^{-4}\ T + 1.000 \times 10^{-6}\ T^2$$
$$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 1.7081 - 1.008 \times 10^{-3}\ T + 4.184 \times 10^{-6}\ T^2$$

46CLA/WAL

POPPY SEED OIL, BLEACHED; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 193. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 146.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	20.09	11.16	46.69
0	32	68.58	38.10	159.41
25	77	89.39	49.66	207.78
50	122	110.11	61.17	255.94
55	131	114.30	63.50	265.68

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

$L_f = 33.3$ Btu lb^{-1}
$L_f = 18.5$ cal g^{-1}
$L_f = 77.4$ J g^{-1}

55RIE

RAPE OIL, REFINED; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 175. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 105.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	16.69	9.27	38.79
0	32	47.75	26.53	111.00
25	77	91.10	50.61	211.75
50	122	112.46	62.48	261.42
55	131	116.77	64.87	271.42

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

$L_f = 35.6$ Btu lb^{-1}
$L_f = 19.8$ cal g^{-1}
$L_f = 82.8$ J g^{-1}

55RIE

RAPESEED OIL; liquid; Material was extracted from industrially stored oil seeds and the acid value was 10.77 mg KOH/g. The specific gravity (15/15°C) = 0.9134. Fatty acids found in the oil: palmitic (3.84%), palmitoleic (0.32%), stearic (1.49%), oleic (14.77%), linoleic (15.12%), linolenic (6.29%), eicosenoic (9.44%), and erucic (47.93%).

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 17487 Btu lb^{-1}
q_v(gross) = 9715 cal g^{-1}
q_v(gross) = 40648 J g^{-1}

75KOM/DAN

RAPESEED OIL; liquid; The vegetable oil has a chemical composition of up to 3 fatty acids linked to a glycerine molecule with ester linkages; the fatty acid composition in percent by weight is palmitic = 3.49, stearic = 0.85, oleic = 64.40, linoleic = 22.30, and linolenic = 8.23. The acid value (number of mg of KOH needed to neutralize free fatty acids in 1 g sample) = 1.14, the phosphorus = 18.0 ppm, peroxide value (milliequivalents of peroxide per 1000 g sample that oxidize KI during test conditions) = 30.2, water and sediment (% by volume) = trace, carbon residue (% by weight) = 0.30, ash (% by weight) = 0.054, and sulfur (% by weight) = 0.01. Density = 0.9115 kg/L.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 17083 Btu lb^{-1}
q_V(gross) = 9491 cal g^{-1}
q_V(gross) = 39709 J g^{-1}

82GOE/SCH

RYE OIL; liquid; oil extracted from rye grain, *Secale cereale*.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 16780 Btu lb^{-1}
q_V(gross) = 9320 cal g^{-1}
q_V(gross) = 38990 J g^{-1}

obtained by ether extraction

q_V(gross) = 16560 Btu lb^{-1}
q_V(gross) = 9200 cal g^{-1}
q_V(gross) = 38495 J g^{-1}

55MER/WAT

SAFFLOWER OIL; liquid; The vegetable oil has a chemical composition of up to 3 fatty acids linked to a glycerine molecule with ester linkages; the fatty acid composition in percent by weight is palmitic = 8.60, stearic = 1.93, oleic = 11.58, and linoleic = 77.89. The acid value (number of mg of KOH needed to neutralize free fatty acids in 1 g sample) = 0.70, the phosphorus = 20.0 ppm, peroxide value (milliequivalents of peroxide per 1000 g sample that oxidize KI during test conditions) = 56.4, water and sediment (% by volume) = trace, carbon residue (% by weight) = 0.25, ash (% by weight) = 0.006, and sulfur (% by weight) = 0.01. Density = 0.9144 kg/L.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 17001 Btu lb^{-1}
q_V(gross) = 9445 cal g^{-1}
q_V(gross) = 39519 J g^{-1}

82GOE/SCH

SESAME OIL; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 189. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 110.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature (°C)	(°F)	H°(t)-H°(-50°C) Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	18.47	10.26	42.93
0	32	64.40	35.78	149.70
25	77	86.83	48.24	201.84
50	122	107.89	59.94	250.79
55	131	112.19	62.33	260.79

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

$L_f = 29.3$ Btu lb^{-1}
$L_f = 16.3$ cal g^{-1}
$L_f = 68.2$ J g^{-1}

55RIE

SESAME OIL; liquid; The vegetable oil has a chemical composition of up to 3 fatty acids linked to a glycerine molecule with ester linkages; the fatty acid composition in percent by weight is palmitic = 13.10, stearic = 3.92, oleic = 52.84, and linoleic = 30.14. The acid value (number of mg of KOH needed to neutralize free fatty acids in 1 g sample) = 4.96, the phosphorus = 10.0 ppm, peroxide value (milliequivalents of peroxide per 1000 g sample that oxidize KI during test conditions) = 22.4, water and sediment (% by volume) = trace, carbon residue (% by weight) = 0.25, ash (% by weight) = 0.01, and sulfur (% by weight) = 0.01. Density = 0.9133 kg/L.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 16928 Btu lb^{-1}
q_v(gross) = 9405 cal g^{-1}
q_v(gross) = 39349 J g^{-1}

82GOE/SCH

SOYBEAN OIL; liquid; the bean of *Soia hispida (Leguminosae)*; average composition: proteins, 40%; oils, 18%; phosphatides, 2%; remainder urease, raffinose, stachyose, saponins, phytosterins, and isoflavone; density is 0.925 g cm^{-3} at 15°C (50°F). Saponification number 189-193.5; iodine number 122-134.

specific heat: sample was heated at 100°C (212°F) for 3 to 6 hours under a pressure of 2-3 mm of Hg to remove moisture.

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.47779 + 5.2622 \times 10^{-4}\ T - 4.8470 \times 10^{-7}\ T^2 + 9.7171 \times 10^{-10}\ T^3$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.03911 + 2.858 \times 10^{-3}\ T - 5.912 \times 10^{-6}\ T^2 + 5.667 \times 10^{-9}\ T^3$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.16362 + 1.1957 \times 10^{-2}\ T - 2.474 \times 10^{-5}\ T^2 + 2.371 \times 10^{-8}\ T^3$

46CLA/WAL

SOYBEAN OIL; liquid; The vegetable oil has a chemical composition of up to 3 fatty acids linked to a glycerine molecule with ester linkages; the fatty acid composition in percent by weight is palmitic = 11.75, stearic = 3.15, oleic = 22.26, linoleic = 55.53, and linolenic = 6.31. The acid value (number of mg of KOH needed to neutralize free fatty acids in 1 g sample) = 0.20, the phosphorus □ 32.0 ppm, peroxide value (milliequivalents of peroxide per 1000 g sample that oxidize KI during test conditions) = 44.5, water and sediment (% by volume) = trace, carbon residue (% by weight) = 0.27, ash (% by weight) = 0.01, and sulfur (% by weight) = 0.01. Density = 0.9138 kg/L.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 17046 Btu lb^{-1}
q_v(gross) □ 9470 cal g^{-1}
q_v(gross) = 39623 J g^{-1}

82GOE/SCH

SOYBEAN OIL, REFINED; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 190. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 133.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature		H°(t)-H°(-50°C)		
(°C)	(°F)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	18.34	10.19	42.64
0	32	65.52	36.40	152.30
25	77	87.73	48.74	203.93
50	122	108.74	60.41	252.76
55	131	112.95	62.75	262.55

(more)

SOYBEAN OIL, REFINED - Continued

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

$L_f = 32.2$ Btu lb^{-1}
$L_f = 17.9$ cal g^{-1}
$L_f = 74.9$ J g^{-1}

55RIE

SUNFLOWER OIL; liquid; The vegetable oil has a chemical composition of up to 3 fatty acids linked to a glycerine molecule with ester linkages; the fatty acid composition in percent by weight is palmitic = 6.08, stearic = 3.26, oleic = 16.93, and linoleic = 73.73. The acid value (number of mg of KOH needed to neutralize free fatty acids in 1 g sample) = 0.15, the phosphorus = 15.0 ppm, peroxide value (milliequivalents of peroxide per 1000 g sample that oxidize KI during test conditions) = 10.7, water and sediment (% by volume) = trace, carbon residue (% by weight) = 0.23, ash (% by weight) = 0.01, and sulfur (% by weight) = 0.01. Density = 0.9161 kg/L.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 17026 Btu lb^{-1}
q_v(gross) = 9459 cal g^{-1}
q_v(gross) = 39575 J g^{-1}

82GOE/SCH

SUNFLOWER, SEED OIL; liquid; Material was extracted from industrially stored oil seeds and the acid value was 3.81 mg KOH/g. Specific gravity (15/15°C) = 0.9208. Fatty acids found in the oil: palmitic (7.06%), stearic (9.41%), oleic (23.33%), linoleic (56.66%), and linolenic (2.10%).

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 17226 Btu lb^{-1}
q_v(gross) = 9570 cal g^{-1}
q_v(gross) = 40041 J g^{-1}

75KOM/DAN

SUNFLOWER OIL, UNREFINED; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 186. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 135.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature (°C)	temperature (°F)	H°(t)-H°(-50°C) Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	16.92	9.40	39.33
0	32	69.48	38.60	161.50
25	77	90.14	50.08	209.53
50	122	111.22	61.79	258.53
55	131	115.47	64.15	268.40

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 34.2 Btu lb^{-1}
L_f = 19.0 cal g^{-1}
L_f = 79.5 J g^{-1}

55RIE

TUNG OIL; liquid; a yellow drying oil from the nuts of the trees *Aleurites cordata* and *Aleurites fordii*; glycerides of eleostearic (~80%); palmitic (~4%); stearic (~1%); and oleic (~15%) acids; density, 0.936-0.942 g cm^{-3}; before measurement, oil was heated at 100°C (212°F) for 3 to 6 hours at 2-3 mm of Hg pressure to remove moisture. Iodine number 154.4.

specific heat: 293-473 K (68°-392°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.37651 + 7.9928 \times 10^{-4}\ T - 1.9479 \times 10^{-6}\ T^2 + 2.0881 \times 10^{-9}\ T^3$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = -0.6053 + 7.0447 \times 10^{-3}\ T - 1.5641 \times 10^{-5}\ T^2 + 1.2178 \times 10^{-8}\ T^3$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = -2.5324 + 2.9475 \times 10^{-2}\ T - 6.4687 \times 10^{-5}\ T^2 + 5.0954 \times 10^{-8}\ T^3$

46CLA/WAL

WHEAT OIL; liquid; from wheat grain, *Triticum aestivum*.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 16850 Btu lb^{-1}
q_V(gross) = 9360 cal g^{-1}
q_V(gross) = 39162 J g^{-1}

oil obtained by ether extraction

q_V(gross) = 16330 Btu lb^{-1}
q_V(gross) = 9070 cal g^{-1}
q_V(gross) = 37950 J g^{-1}

55MER/WAT

Woody and Tree Materials

ALDER, EUROPEAN BLACK; *Alnus glutinosa*; solid; Each tree was separated into small parts (being less than 0.64 cm (1/4 in.) in diameter and roughly equivalent to tops and branches) and large parts with the weighted proportion of small (25%) and large (75%) material in the whole tree. Overall mean specific gravity for whole tree = 0.37 (oven dry weight and green volume). Bark proportion of whole tree = 23%.

gross heat of combustion: oven-dried, assume values refer to room temperature.

small parts

$q_v(\text{gross}) = 7965 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 4425 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 18514 \text{ J g}^{-1}$

large parts

$q_v(\text{gross}) = 8248 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 4582 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 19171 \text{ J g}^{-1}$

whole tree

$q_v(\text{gross}) = 8177 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 4543 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 19008 \text{ J g}^{-1}$

81GEY

ALDER, RED; BARK; *Alnus rubra*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 3.1%; moisture content = 5.8%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

$q_v(\text{gross}) = 7947 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 4415 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 18472 \text{ J g}^{-1}$

55CHA/MIT

ASH; *Fraxinus excelsior*; solid; ultimate analysis: carbon, 49.18%; hydrogen, 6.27%; nitrogen, 0.07%; ash, 0.57%.

gross heat of combustion: 20°C (68°F); air-dried at 110°-115°C (230°-240°F), ash free.

$q_v(\text{gross}) = 8507 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 4726 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 19774 \text{ J g}^{-1}$

1883GOT

ASH, GREEN; ***Fraxinus pennsylvanica*****;** solid; Mean age = 12 years, mean basal stem diameter = 7.0 cm, mean stem bark (proportion of dry weight) = 12.3%, ash content (proportion of oven dry weight) of components of sample: wood = 0.71%, branches = 1.9%, twigs = 2.2%, bark = 6.7% and leaves = 4.9%.

gross heat of combustion: oven dry weight basis; assume values refer to room temperature.

wood:

q_v(gross) = 8582 Btu lb^{-1}
q_v(gross) = 4768 cal g^{-1}
q_v(gross) = 19949 J g^{-1}

bark:

q_v(gross) = 8312 Btu lb^{-1}
q_v(gross) = 4618 cal g^{-1}
q_v(gross) = 19322 J g^{-1}

branches:

q_v(gross) = 8743 Btu lb^{-1}
q_v(gross) = 4857 cal g^{-1}
q_v(gross) = 20322 J g^{-1}

twigs:

q_v(gross) = 8672 Btu lb^{-1}
q_v(gross) = 4818 cal g^{-1}
q_v(gross) = 20159 J g^{-1}

leaves:

q_v(gross) = 9214 Btu lb^{-1}
q_v(gross) = 5119 cal g^{-1}
q_v(gross) = 21418 J g^{-1}

79NEE/STE

ASH, GREEN; ***Fraxinus pennsylvanica*****;** solid; Material was collected from the southern Atlantic and Gulf coastal plains in bottom-, swamp- and wet flat-land natural stand sites. Samples were dried at 70°C (158°F) to a constant weight; reported values were averaged over all positions of similar plant tissue for each tree and six trees per species were used.

gross heat of combustion: assume values refer to room temperature; values are on a dry weight basis.

bole wood

q_v(gross) = 8356 Btu lb^{-1}
q_v(gross) = 4642 cal g^{-1}
q_v(gross) = 19422 J g^{-1}

bole bark

q_v(gross) = 8235 Btu lb^{-1}
q_v(gross) = 4575 cal g^{-1}
q_v(gross) = 19142 J g^{-1}

foliage

q_v(gross) = 8422 Btu lb^{-1}
q_v(gross) = 4679 cal g^{-1}
q_v(gross) = 19577 J g^{-1}

branch wood

q_v(gross) = 8449 Btu lb^{-1}
q_v(gross) = 4694 cal g^{-1}
q_v(gross) = 19640 J g^{-1}

branch bark

q_v(gross) = 8426 Btu lb^{-1}
q_v(gross) = 4681 cal g^{-1}
q_v(gross) = 19585 J g^{-1}

82GOW/FRE

ASH, WHITE; ***Fraxinus americana*****;** solid; Material came from various locations in New Hampshire. Bole samples were composed of cross sections taken from four positions along length of each tree (at the base, one-third, two-thirds, one at top of the stem). Branch samples were composed of cross sections taken from four positions along length of each of four branches (one branch from four positions in the live crown of the tree). Bark was removed from half of each bole and branch sample and all samples were oven-dried at 85°C (185°F) to a constant weight.

gross heat of combustion: Assume values refer to room temperature, thermochemical calorie used and values were expressed on a dry matter basis and adjusted for heat of formation of nitric acid. All tests were made at 99% confidence level and numbers in parentheses are standard errors.

bole with bark

q_V(gross) = 8433 (108) Btu lb^{-1}
q_V(gross) = 4685 (60) cal g^{-1}
q_V(gross) = 19602 (251) J g^{-1}

bole without bark

q_V(gross) = 8395 (59) Btu lb^{-1}
q_V(gross) = 4664 (33) cal g^{-1}
q_V(gross) = 190514 (138) J g^{-1}

foliage

q_V(gross) = 8638 Btu lb^{-1}
q_V(gross) = 4799 cal g^{-1}
q_V(gross) = 20079 J g^{-1}

branch with bark

q_V(gross) = 8654 (128) Btu lb^{-1}
q_V(gross) = 4808 (71) cal g^{-1}
q_V(gross) = 20117 (297) J g^{-1}

branch without bark

q_V(gross) = 8680 (175) Btu lb^{-1}
q_V(gross) = 4822 (97) cal g^{-1}
q_V(gross) = 20175 (406) J g^{-1}

81MUS/HOC

ASH, WHITE; ***Fraxinus americana*****;** solid; air-dried at 105°-110°C (221°-230°F); density, 0.63 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} °F^{-1}) = 0.327
C_p(cal g^{-1} K^{-1}) = 0.327
C_p(J g^{-1} K^{-1}) = 1.368

12DUN

ASPEN, QUAKING; *Populus tremuloides*; solid; air-dried at 105°-110°C (221°-230°F), density, 0.43 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} $°F^{-1}$) = 0.329
C_p(cal g^{-1} K^{-1}) = 0.329
C_p(J g^{-1} K^{-1}) = 1.377

12DUN

ASPEN, QUAKING; BARK; *Populus tremuloides*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 2.8%; moisture content = 5.5%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

q_v(gross) = 8433 Btu lb^{-1}
q_v(gross) = 4685 cal g^{-1}
q_v(gross) = 19602 J g^{-1}

55CHA/MIT

ASPEN, QUAKING; FOLIAGE; *Populus tremuloides*; solid; freeze-dried to < 10% moisture content. Composition is ash = 4.97% and char yield = 27.8%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 9740 Btu lb^{-1}	q_v(gross) ⊟ 13940 Btu lb^{-1}
q_v(gross) = 5410 cal g^{-1}	q_v(gross) ⊟ 7740 cal g^{-1}
q_v(gross) = 22650 J g^{-1}	q_v(gross) ⊟ 32400 J g^{-1}

82SUS

ASPEN, TREMBLING; *Populus tremuloides*; solid; Material came from various locations in New Hampshire. Bole samples were composed of cross sections taken from four positions along length of each tree (at the base, one-third, two-thirds, and at top of the stem). Branch samples were composed of cross sections taken from four positions along length of each of four branches (one branch from four positions in the live crown of the tree). Bark was removed from half of each bole and branch sample and all samples were oven-dried at 85°C (185°F) to a constant weight.

gross heat of combustion: Assume values refer to room temperature, thermochemical calorie used and values were expressed on a dry matter basis and adjusted for heat of formation of nitric acid. All tests were made at 99% confidence level and numbers in parentheses are standard errors.

bole with bark

q_v(gross) = 8782 (50) Btu lb^{-1}
q_v(gross) = 4879 (28) cal g^{-1}
q_v(gross) = 20414 (117) J g^{-1}

branch with bark

q_v(gross) = 8957 (61) Btu lb^{-1}
q_v(gross) = 4976 (34) cal g^{-1}
q_v(gross) = 20820 (142) J g^{-1}

bole without bark

q_v(gross) = 8905 (56) Btu lb^{-1}
q_v(gross) = 4947 (31) cal g^{-1}
q_v(gross) = 20698 (130) J g^{-1}

branch without bark

q_v(gross) = 8773 (32) Btu lb^{-1}
q_v(gross) = 4874 (18) cal g^{-1}
q_v(gross) = 20393 (75) J g^{-1}

foliage

q_v(gross) = 9648 Btu lb^{-1}
q_v(gross) = 5360 cal g^{-1}
q_v(gross) = 22426 J g^{-1}

81MUS/HOC

BEECH; *Fagus atropunicea*; solid; air-dried at 105°-110°C (221°-230°F); density, 0.75 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} $°F^{-1}$) = 0.326
C_p(cal g^{-1} K^{-1}) = 0.326
C_p(J g^{-1} K^{-1}) = 1.364

12DUN

BEECH; *Fagus silvatiea*; solid; ultimate analysis: carbon, 49.06%; hydrogen, 6.11%; nitrogen, 0.09%; ash, 0.57%.

gross heat of combustion: 20°C (68°F), air-dried at 110°-115°C (230°-240°F), ash free.

$q_V(\text{gross}) = 8624 \text{ Btu lb}^{-1}$
$q_V(\text{gross}) = 4791 \text{ cal g}^{-1}$
$q_V(\text{gross}) = 20046 \text{ J g}^{-1}$

1883GOT

BEEFWOOD (SHE-OAK); *Casuarina equisetifolia*; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 78.94, ash content = 1.40, and fixed carbon = 19.66. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 48.61, hydrogen = 5.83, oxygen = 43.36, nitrogen = 0.59, sulfur = 0.02, chlorine = 0.16, and residue (ash) = 1.43.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

$q_V(\text{gross}) = 8363 \text{ Btu lb}^{-1}$
$q_V(\text{gross}) = 4646 \text{ cal g}^{-1}$
$q_V(\text{gross}) = 19440 \text{ J g}^{-1}$

net heat of combustion: assume values refer to room temperature.

$q_V(\text{net}) = 7856 \text{ Btu lb}^{-1}$
$q_V(\text{net}) = 4364 \text{ cal g}^{-1}$
$q_V(\text{net}) = 18260 \text{ J g}^{-1}$

85JEN/EBE

BIRCH; *Betula alba*; solid; ultimate analysis: carbon, 48.88%; hydrogen, 6.06%; nitrogen, 0.10%; ash, 0.29%; oxygen, 44.67%.

gross heat of combustion: 20°C (68°F), air-dried at 110°-115°C (230°-240°F), ash free.

$q_v(\text{gross}) = 8588\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4771\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19962\ \text{J g}^{-1}$

1883GOT

air dried one hour at 105°C (221°F)

$q_v(\text{gross}) = 8458\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4699\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19661\ \text{J g}^{-1}$

22PAR/DAV

BIRCH, PAPER; *Betula papyrifera*; solid; Material came from various locations in New Hampshire. Bole samples were composed of cross sections taken from four positions along length of each tree (at the base, one-third, two-thirds, and at top of the stem). Branch samples were composed of cross sections taken from four positions along length of each of four branches (one branch from four positions in the live crown of the tree). Bark was removed from half of each bole and branch sample and all samples were oven-dried at 85°C (185°F) to a constant weight.

gross heat of combustion: Assume values refer to room temperature, thermochemical calorie used and values were expressed on a dry matter basis and adjusted for heat of formation of nitric acid. All tests were made at 99% confidence level and numbers in parentheses are standard errors.

bole with bark

$q_v(\text{gross}) = 9207\ (56)\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 5115\ (31)\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 21401\ (130)\ \text{J g}^{-1}$

bole without bark

$q_v(\text{gross}) = 8948\ (86)\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4971\ (48)\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 20799\ (201)\ \text{J g}^{-1}$

foliage

$q_v(\text{gross}) = 9428\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 5238\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 21916\ \text{J g}^{-1}$

branch with bark

$q_v(\text{gross}) = 9245\ (70)\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 5136\ (39)\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 21489\ (163)\ \text{J g}^{-1}$

branch without bark

$q_v(\text{gross}) = 9074\ (54)\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 5041\ (30)\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 21092\ (126)\ \text{J g}^{-1}$

81MUS/HOC

BIRCH, PAPER; BARK; *Betula papyrifera*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 1.5%; moisture content = 4.8%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

q_v(gross) = 9434 Btu lb^{-1}
q_v(gross) = 5241 cal g^{-1}
q_v(gross) = 21928 J g^{-1}

55CHA/MIT

BIRCH, YELLOW; *Betula alleghaniensis*; solid; Material came from various locations in New Hampshire. Bole samples were composed of cross sections taken from four positions along length of each tree (at the base, one-third, two-thirds, one at top of the stem). Branch samples were composed of cross sections taken from four positions along length of each of four branches (one branch from four positions in the live crown of the tree). Bark was removed from half of each bole and branch sample and all samples were oven-dried at 85°C (185°F) to a constant weight.

gross heat of combustion: Assume values refer to room temperature, thermochemical calorie used and values were expressed on a dry matter basis and adjusted for heat of formation of nitric acid. All tests were made at 99% confidence level and numbers in parentheses are standard errors.

bole with bark

q_v(gross) = 8838 (175) Btu lb^{-1}
q_v(gross) = 4910 (97) cal g^{-1}
q_v(gross) = 20543 (406) J g^{-1}

bole without bark

q_v(gross) = 8498 (133) Btu lb^{-1}
q_v(gross) = 4721 (74) cal g^{-1}
q_v(gross) = 19753 (310) J g^{-1}

foliage

q_v(gross) = 8503 Btu lb^{-1}
q_v(gross) = 4724 cal g^{-1}
q_v(gross) = 19765 J g^{-1}

branch with bark

q_v(gross) = 9002 (247) Btu lb^{-1}
q_v(gross) = 5001 (137) cal g^{-1}
q_v(gross) = 20924 (573) J g^{-1}

branch without bark

q_v(gross) = 8917 (101) Btu lb^{-1}
q_v(gross) = 4954 (56) cal g^{-1}
q_v(gross) = 20728 (234) J g^{-1}

81MUS/HOC

BIRCH, YELLOW; BARK; *Betula alleghaniensis*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 1.7%; moisture content = 5.2%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

$q_v(\text{gross}) = 9076\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 5042\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 21096\ \text{J g}^{-1}$

55CHA/MIT

BLACKGUM; *Nyssa sylvatica*; solid; air-dried at 105°-110°C (221°-230°F); density, 0.52 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.325$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.325$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 1.360$

12DUN

BLACKGUM; *Nyssa sylvatica*; solid; Material was collected from the southern Atlantic and Gulf coastal plains in bottom-, swamp- and wet flat-land natural stand sites. Samples were dried at 70°C (158°F) to a constant weight; reported values were averaged over all positions of similar plant tissue for each tree and six trees per species were used.

gross heat of combustion: assume values refer to room temperature; values are on a dry weight basis.

bole wood

$q_v(\text{gross}) = 8465\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4703\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19677\ \text{J g}^{-1}$

bole bark

$q_v(\text{gross}) = 8397\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4665\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19518\ \text{J g}^{-1}$

foliage

$q_v(\text{gross}) = 8991\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4995\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 20899\ \text{J g}^{-1}$

branch wood

$q_v(\text{gross}) = 8564\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4758\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19907\ \text{J g}^{-1}$

branch bark

$q_v(\text{gross}) = 8456\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4809\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 20121\ \text{J g}^{-1}$

82GOW/FRE

BLACKGUM, BARK; *Nyssa sylvatica*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 7.2%; moisture content = 6.0%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

$q_V(\text{gross}) = 7936 \text{ Btu lb}^{-1}$
$q_V(\text{gross}) = 4409 \text{ cal g}^{-1}$
$q_V(\text{gross}) = 18447 \text{ J g}^{-1}$

55CHA/MIT

BOXELDER; *Acer negundo*; solid; Each tree was separated into small parts (being less than 0.64 cm (1/4 in.) in diameter and roughly equivalent to tops and branches) and large parts with the weighted proportion of small (25%) and large (75%) material in the whole tree. Overall mean specific gravity for whole tree = 0.36 (oven dry weight and green volume). Bark proportion of whole tree = 14%.

gross heat of combustion: oven-dried, assume values refer to room temperature.

small parts

$q_V(\text{gross}) = 7981 \text{ Btu lb}^{-1}$
$q_V(\text{gross}) = 4434 \text{ cal g}^{-1}$
$q_V(\text{gross}) = 18552 \text{ J g}^{-1}$

large parts

$q_V(\text{gross}) = 8190 \text{ Btu lb}^{-1}$
$q_V(\text{gross}) = 4550 \text{ cal g}^{-1}$
$q_V(\text{gross}) = 19037 \text{ J g}^{-1}$

whole tree

$q_V(\text{gross}) = 8138 \text{ Btu lb}^{-1}$
$q_V(\text{gross}) = 4521 \text{ cal g}^{-1}$
$q_V(\text{gross}) = 18916 \text{ J g}^{-1}$

81GEY

BOXELDER; ***Acer negundo*****;** solid; mean age = 11 years, mean basal stem diameter = 8.97 cm, mean stem bark (proportion of dry weight) = 9.13%, ash content (proportion of oven dry weight) of components of sample: wood = 0.78%, branches = 1.6%, twigs = 2.9%, bark = 9.5%, and leaves = 6.2%.

gross heat of combustion: oven dry weight basis; assume values refer to room temperature.

wood:

q_v(gross) = 8809 Btu lb^{-1}
q_v(gross) = 4894 cal g^{-1}
q_v(gross) = 20477 J g^{-1}

bark:

q_v(gross) = 7778 Btu lb^{-1}
q_v(gross) = 4321 cal g^{-1}
q_v(gross) = 18079 J g^{-1}

branches:

q_v(gross) = 8786 Btu lb^{-1}
q_v(gross) = 4881 cal g^{-1}
q_v(gross) = 20422 J g^{-1}

twigs:

q_v(gross) = 8708 Btu lb^{-1}
q_v(gross) = 4838 cal g^{-1}
q_v(gross) = 20242 J g^{-1}

leaves:

q_v(gross) = 9050 Btu lb^{-1}
q_v(gross) = 5028 cal g^{-1}
q_v(gross) = 21037 J g^{-1}

79NEE/STE

CABBAGE WOOD; ***Ligustrum vulgare*****;** solid; Material is a shrub, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content was determined at 500°C (932°F) while the temperature was increased stepwise. Ash content of stem and branch wood = 0.7%; stem and branch bark = 4.9%; leaf = 9.0%; root = 6.8%.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
stem and branch wood (4 measurements)				
q_v(gross) =	8318	8375	57.2	Btu lb^{-1}
q_v(gross) =	4621	4653	31.8	cal g^{-1}
q_v(gross) =	19334	19468	133	J g^{-1}
stem and branch bark (4 measurements)				
q_v(gross) =	8194	8624	96.7	Btu lb^{-1}
q_v(gross) =	4552	4791	53.7	cal g^{-1}
q_v(gross) =	19046	20046	225	cal g^{-1}

(more)

CABBAGE WOOD - Continued

leaf (5 measurements)

	dry weight basis	ash-free dry weight basis	std dev. of mean	
q_v(gross) =	8438	9268	67.7	Btu lb^{-1}
q_v(gross) =	4688	5149	37.6	cal g^{-1}
q_v(gross) =	19615	21543	157	J g^{-1}

root (4 measurements)

	dry weight basis	ash-free dry weight basis	std dev. of mean	
q_v(gross) =	8168	8771	51.5	Btu lb^{-1}
q_v(gross) =	4538	4873	28.6	cal g^{-1}
q_v(gross) =	18987	20389	120	J g^{-1}

75PAP

CEDAR, RED; *Juniperus virginiana*; solid; air-dried at 105°-110°C (221°-230°F); density, 0.46 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} °F^{-1}) = 0.324
C_p(cal g^{-1} K^{-1}) = 0.324
C_p(J g^{-1} K^{-1}) = 1.356

12DUN

CHAMISE, FOLIAGE; *Adenostoma fasciculatum*; solid; freeze dried to < 10% moisture content. Composition is ash = 3.50% and char yield = 28.6%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 9430 Btu lb^{-1}	q_v(gross) = 13490 Btu lb^{-1}
q_v(gross) = 5240 cal g^{-1}	q_v(gross) = 7490 cal g^{-1}
q_v(gross) = 21910 J g^{-1}	q_v(gross) = 31350 J g^{-1}

82SUS

CHAPARRAL; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 75.19, ash content = 6.13, and fixed carbon = 18.68. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 46.90, hydrogen = 5.08, oxygen = 40.17, nitrogen = 0.54, sulfur = 0.03, chlorine = 0.02, and residue (ash) = 7.26.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

$q_V(\text{gross}) = 8006\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 4448\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 18610\ \text{J g}^{-1}$

net heat of combustion: assume values refer to room temperature.

$q_V(\text{net}) = 7563\ \text{Btu lb}^{-1}$
$q_V(\text{net}) = 4202\ \text{cal g}^{-1}$
$q_V(\text{net}) = 17580\ \text{J g}^{-1}$

85JEN/EBE

CHERRY; genus *Prunus*; solid.

gross heat of combustion: assume values refer to room temperature.

as received: 8.85% moisture	air dried one hour at 105°C (221°F)
$q_V(\text{gross}) = 7866\ \text{Btu lb}^{-1}$	$q_V(\text{gross}) = 8629\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 4370\ \text{cal g}^{-1}$	$q_V(\text{gross}) = 4794\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 18282\ \text{J g}^{-1}$	$q_V(\text{gross}) = 20058\ \text{J g}^{-1}$

1883GOT

CHERRY, BLACK; *Prunus serotina*; solid; mean age = 12.3 years, mean basal stem diameter = 8.9 cm, mean stem bark (proportion of dry weight) = 9.9%, ash content (proportion of oven dry weight) of components of sample: wood = 0.41%, branches = 0.8%, twigs = 1.7%, bark = 4.2%, and leaves = 5.6%.

gross heat of combustion: oven dry weight basis; assume values refer to room temperature.

wood:

q_v(gross) = 8579 Btu lb^{-1}
q_v(gross) = 4766 cal g^{-1}
q_v(gross) = 19941 J g^{-1}

bark:

q_v(gross) = 8906 Btu lb^{-1}
q_v(gross) = 4948 cal g^{-1}
q_v(gross) = 20702 J g^{-1}

branches:

q_v(gross) = 8714 Btu lb^{-1}
q_v(gross) = 4841 cal g^{-1}
q_v(gross) = 20255 J g^{-1}

twigs:

q_v(gross) = 8759 Btu lb^{-1}
q_v(gross) = 4866 cal g^{-1}
q_v(gross) = 20359 J g^{-1}

leaves:

q_v(gross) = 9418 Btu lb^{-1}
q_v(gross) = 5232 cal g^{-1}
q_v(gross) = 21891 J g^{-1}

79NEE/STE

CHERRY, CORNELIAN; *Cornus mas*; solid; Material is a tree, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content was determined at 500°C (932°F) while the temperature was increased stepwise. Ash content of stem and branch wood = 0.7%; stem and branch bark = 10.0%; leaf = 14.0%; root = 8.3%.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
stem and branch wood (3 measurements)				
q_v(gross) =	8404	8462	20.3	Btu lb^{-1}
q_v(gross) =	4669	4701	11.3	cal g^{-1}
q_v(gross) =	19535	19669	47.3	J g^{-1}
stem and branch bark (4 measurements)				
q_v(gross) =	8172	8987	29.5	Btu lb^{-1}
q_v(gross) =	4540	4993	16.4	cal g^{-1}
q_v(gross) =	18995	20891	68.6	J g^{-1}

(more)

CHERRY, CORNELIAN - Continued

	dry weight basis	ash-free dry weight basis	std dev. of mean	
leaf (5 measurements)				
q_v(gross) =	7177	8343	66.8	Btu lb^{-1}
q_v(gross) =	3987	4635	37.1	cal g^{-1}
q_v(gross) =	16682	19393	155	J g^{-1}
root (4 measurements)				
q_v(gross) =	8008	8726	23.4	Btu lb^{-1}
q_v(gross) =	4449	4848	13.0	cal g^{-1}
q_v(gross) =	18615	20284	54.4	J g^{-1}

75PAP

CHESTNUT; *Castanea dentata*; solid; air-dried at 105°-110°C (221°-230°F); density, 0.32 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} $°F^{-1}$) = 0.317
C_p(cal g^{-1} K^{-1}) = 0.317
C_p(J g^{-1} K^{-1}) = 1.326

12DUN

COCOBOLA NEGRA; *Lecythis costariconsis*; solid; from Costa Rica; air-dried at 105°-110°C (221°-230°F); density, 0.92 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} $°F^{-1}$) = 0.327
C_p(cal g^{-1} K^{-1}) = 0.327
C_p(J g^{-1} K^{-1}) = 1.368

12DUN

COTTONWOOD, MISSOURI; ***Populus deltoides*****;** solid; Each tree was separated into small parts (being less than 0.64 cm (1/4 in.) in diameter and roughly equivalent to tops and branches) and large parts with the weighted proportion of small (25%) and large (75%) material in the whole tree. Overall mean specific gravity for whole tree = 0.32 (oven dry weight and green volume). Bark proportion of whole tree = 19%.

gross heat of combustion: oven-dried, assume values refer to room temperature.

small parts

$q_v(\text{gross}) = 8451\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4695\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19644\ \text{J g}^{-1}$

large parts

$q_v(\text{gross}) = 7949\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4416\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 18477\ \text{J g}^{-1}$

whole tree

$q_v(\text{gross}) = 8075\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4486\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 18769\ \text{J g}^{-1}$

81GEY

COTTONWOOD, NEBRASKA; ***Populus deltoides*****;** solid; Each tree was separated into small parts (being less than 0.64 cm (1/4 in.) in diameter and roughly equivalent to tops and branches) and large parts with the weighted proportion of small (25%) and large (75%) material in the whole tree. Overall mean specific gravity for whole tree = 0.36 (oven dry weight and green volume). Bark proportion of whole tree = 28%.

gross heat of combustion: oven-dried, assume values refer to room temperature.

small parts

$q_v(\text{gross}) = 7893\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4385\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 18347\ \text{J g}^{-1}$

large parts

$q_v(\text{gross}) = 7718\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4288\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 17941\ \text{J g}^{-1}$

whole tree

$q_v(\text{gross}) = 7762\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4312\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 18041\ \text{J g}^{-1}$

81GEY

DOGWOOD, BLOOD-TWIG; *Cornus sanguinea*; solid; Material is a shrub, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content was determined at 500°C (932°F) while the temperature was increased stepwise. Ash content of stem and branch wood = 0.6%; stem and branch bark = 6.3%; leaf = 14.1%; root = 8.3%.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
stem and branch wood (3 measurements)				
q_V(gross) =	8300	8341	50.6	Btu lb^{-1}
q_V(gross) =	4611	4634	28.1	cal g^{-1}
q_V(gross) =	19292	19389	118	J g^{-1}
stem and branch bark (5 measurements)				
q_V(gross) =	8525	9104	48.4	Btu lb^{-1}
q_V(gross) =	4736	6058	26.9	cal g^{-1}
q_V(gross) =	19815	21163	113	J g^{-1}
leaf (5 measurements)				
q_V(gross) =	7414	8633	49.3	Btu lb^{-1}
q_V(gross) =	4119	4796	27.4	cal g^{-1}
q_V(gross) =	17234	20066	115	J g^{-1}
root (3 measurements)				
q_V(gross) =	7861	8570	27.0	Btu lb^{-1}
q_V(gross) =	4367	4761	15.0	cal g^{-1}
q_V(gross) =	18272	19920	62.8	J g^{-1}

75PAP

ELM, AMERICAN; BARK; *Ulmus americana*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 9.5%; moisture content = 6.7%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash content; hence, are on an as-determined basis.

q_V(gross) = 6921 Btu lb^{-1}
q_V(gross) = 3845 cal g^{-1}
q_V(gross) = 16087 J g^{-1}

55CHA/MIT

ELM, WHITE; *Ulmus americana*; solid; air-dried at 105°-110°C (221°-230°F); density, 0.64 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} °F^{-1}) = 0.325
C_p(cal g^{-1} K^{-1}) = 0.325
C_p(J g^{-1} K^{-1}) = 1.360

12DUN

EUCALYPTUS CAMALDULENSIS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 81.42, ash content = 0.76, and fixed carbon = 17.82. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 49.00, hydrogen = 5.87, oxygen = 43.97, nitrogen = 0.30, sulfur = 0.01, chlorine = 0.13, and residue (ash) = 0.72.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8355 Btu lb^{-1}
q_v(gross) = 4641 cal g^{-1}
q_v(gross) = 19420 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7843 Btu lb^{-1}
q_v(net) = 4357 cal g^{-1}
q_v(net) = 18230 J g^{-1}

85JEN/EBE

EUCALYPTUS GLOBULUS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 81.60, ash content = 1.10, and fixed carbon = 17.30. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 48.18, hydrogen = 5.92, oxygen = 44.18, nitrogen = 0.39, sulfur = 0.01, chlorine = 0.20, and residue (ash) = 1.12.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8273 Btu lb^{-1}
q_v(gross) = 4596 cal g^{-1}
q_v(gross) = 19230 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7757 Btu lb^{-1}
q_v(net) = 4309 cal g^{-1}
q_v(net) = 18030 J g^{-1}

85JEN/EBE

EUCALYPTUS GRANDIS; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 82.55, ash content = 0.52, and fixed carbon = 16.93. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 48.33, hydrogen = 5.89, oxygen = 45.13, nitrogen = 0.15, sulfur = 0.01, chlorine = 0.08, and residue (ash) = 0.41.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8325 Btu lb^{-1}
q_v(gross) = 4625 cal g^{-1}
q_v(gross) = 19350 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7808 Btu lb^{-1}
q_v(net) = 4338 cal g^{-1}
q_v(net) = 18150 J g^{-1}

85JEN/EBE

EXCELSIOR, DEAD WOOD; ***Populus spp.***; solid; Dead wood was air-dried at room temperature. Composition is ash = 0.35% and char yield = 15.4%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 8430 Btu lb^{-1}	q_V(gross) = 13930 Btu lb^{-1}
q_V(gross) = 4680 cal g^{-1}	q_V(gross) = 7740 cal g^{-1}
q_V(gross) = 19600 J g^{-1}	q_V(gross) = 32370 J g^{-1}

82SUS

FIR; ***Pinus silvestri***; solid; ultimate analysis: carbon, 50.36%; hydrogen, 5.92%; nitrogen, 0.05%; ash, 0.28%.

gross heat of combustion: 20°C (68°F); air-dried at 110°-115°C (230°-240°F), ash free.

q_V(gross) = 9068 Btu lb^{-1}
q_V(gross) = 5038 cal g^{-1}
q_V(gross) = 21079 J g^{-1}

1883GOT

FIR, BALSAM; BARK; ***Abies balsamea***; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 2.3%; moisture content = 6.5%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

q_V(gross) = 8861 Btu lb^{-1}
q_V(gross) = 4923 cal g^{-1}
q_V(gross) = 20598 J g^{-1}

55CHA/MIT

FIR, BALSAM; NEEDLES; ***Abies balsamea***; solid; Samples were removed from 7-year-old trees and had a concentration (in milligrams per gram ash-free dry weight) of starch = 41.7, total sugar = 130.7, crude fat = 101.0, and nitrogen = 8.8.

gross heat of combustion: values refer to ash-free dry weight and assume values refer to room temperature.

q_V(gross) = 9182 Btu lb^{-1}
q_V(gross) = 5101 cal g^{-1}
q_V(gross) = 21343 J g^{-1}

78SHA/LIT

FIR, DOUGLAS; *Pseudotsuga taxifolia*; solid; air-dried at 105°-110°C (221°-230°F), density, 0.48 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} $°F^{-1}$) = 0.327
C_p(cal g^{-1} K^{-1}) = 0.327
C_p(J g^{-1} K^{-1}) = 1.368

12DUN

FIR, DOUGLAS; *Pseudotsuga menzeisii*; solid; Wood was air-dried at room temperature. Composition is ash = 0.15% and char yield = 20.1%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 8710 Btu lb^{-1}	q_v(gross) = 13720 Btu lb^{-1}
q_v(gross) = 4840 cal g^{-1}	q_v(gross) = 7620 cal g^{-1}
q_v(gross) = 20250 J g^{-1}	q_v(gross) = 31900 J g^{-1}

82SUS

FIR, DOUGLAS; BARK; *Pseudotsuga menzeisii*; solid; Bark samples were air-dried at room temperature. Composition is ash = 1.25% and char yield = 37.2%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 10310 Btu lb^{-1}	q_v(gross) = 12860 Btu lb^{-1}
q_v(gross) = 5730 cal g^{-1}	q_v(gross) = 7140 cal g^{-1}
q_v(gross) = 23960 J g^{-1}	q_v(gross) = 29890 J g^{-1}

82SUS

FIR, DOUGLAS; FOLIAGE; ***Pseudotsuga menzeisii***; solid; freeze-dried to < 10% moisture content. Composition is ash = 4.25% and char yield = 29.2%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 9590 Btu lb^{-1}	q_V(gross) = 13640 Btu lb^{-1}
q_V(gross) = 5330 cal g^{-1}	q_V(gross) = 7580 cal g^{-1}
q_V(gross) = 22300 J g^{-1}	q_V(gross) = 31710 J g^{-1}

82SUS

FIR, DOUGLAS; LUMBER; ***Pseudotsuga menzeisii***; solid; Lumber was air-dried at room temperature. Composition is ash = 0.18% and char yield = 22.2%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 8640 Btu lb^{-1}	q_V(gross) = 13740 Btu lb^{-1}
q_V(gross) = 4800 cal g^{-1}	q_V(gross) = 7630 cal g^{-1}
q_V(gross) = 20090 J g^{-1}	q_V(gross) = 31940 J g^{-1}

82SUS

FIR, DOUGLAS; ROTTEN WOOD; ***Pseudotsuga menzeisii***; solid; Samples were air-dried at room temperature. Composition is ash = 0.16% and char yield = 40.6%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 9920 Btu lb^{-1}	q_V(gross) = 13360 Btu lb^{-1}
q_V(gross) = 5510 cal g^{-1}	q_V(gross) = 7420 cal g^{-1}
q_V(gross) = 23050 J g^{-1}	q_V(gross) = 31050 J g^{-1}

82SUS

FIR, DOUGLAS; STEMS; ***Pseudotsuga menzeisii***; solid; Stem samples were branches < 0.25 in. diameter with foliage removed and freeze-dried to < 10% moisture content. Composition is ash = 2.57% and char yield = 27.9%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 9630 Btu lb^{-1}	q_V(gross) = 13640 Btu lb^{-1}
q_V(gross) = 5350 cal g^{-1}	q_V(gross) = 7580 cal g^{-1}
q_V(gross) = 22380 J g^{-1}	q_V(gross) = 31710 J g^{-1}

82SUS

FIR, GRAND; ***Abies grandis***; solid; Wood sample was air-dried at room temperature. Composition is ash = 0.49% and char yield = 20.7%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 8710 Btu lb^{-1}	q_V(gross) = 13770 Btu lb^{-1}
q_V(gross) = 4840 cal g^{-1}	q_V(gross) = 7650 cal g^{-1}
q_V(gross) = 20250 J g^{-1}	q_V(gross) = 32000 J g^{-1}

82SUS

FIR, WHITE; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 83.17, ash content = 0.25, and fixed carbon = 16.58. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 49.00, hydrogen = 5.98, oxygen = 44.75, nitrogen = 0.05, sulfur = 0.01, chlorine = 0.01, and residue (ash) = 0.02.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_V(gross) = 8583 Btu lb^{-1}
q_V(gross) = 4768 cal g^{-1}
q_V(gross) = 19950 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_V(net) = 8062 Btu lb^{-1}
q_V(net) = 4479 cal g^{-1}
q_V(net) = 18740 J g^{-1}

85JEN/EBE

FIR, WHITE; *Abies concolor*; solid; Wood samples were air-dried at room temperature. Composition is ash = 0.55% and char yield = 22.1%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel

q_V(gross) = 8850 Btu lb^{-1}
q_V(gross) = 4920 cal g^{-1}
q_V(Gross) = 20570 J g^{-1}

char (from 500°C heating)

q_V(gross) = 14270 Btu lb^{-1}
q_V(gross) = 7930 cal g^{-1}
q_V(gross) = 33180 J g^{-1}

82SUS

FIR, WHITE; *Abies concolor*; solid; Material was obtained from Whitaker's Forest in Tulare County, California, with predominant soil series of Shaver sandy loam derived from granitic parent material. The layer was collected from the understory of the forest floor. Average yearly decomposition of the forest floor for white fir is: litter, 6.67%; duff, 1.46%.

gross heat of combustion: assume values refer to room temperature; ash-free.

branch-twig

q_V(gross) = 8990 Btu lb^{-1}
q_V(gross) = 4939 cal g^{-1}
q_V(gross) = 20665 J g^{-1}

litter

q_V(gross) = 9338 Btu lb^{-1}
q_V(gross) = 5188 cal g^{-1}
q_V(gross) = 21707 J g^{-1}

duff

q_V(gross) = 9238 Btu lb^{-1}
q_V(gross) = 5132 cal g^{-1}
q_V(gross) = 21472 J g^{-1}

78AGE/WAK

FIR, WHITE; ROTTEN WOOD; *Abies concolor*; solid; Samples were air-dried at room temperature. Composition is ash = 0.15% and char yield = 21.3%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel

q_V(gross) = 8750 Btu lb^{-1}
q_V(gross) = 4860 cal g^{-1}
q_V(gross) = 20340 J g^{-1}

char (from 500°C heating)

q_V(gross) = 13720 Btu lb^{-1}
q_V(gross) = 7620 cal g^{-1}
q_V(gross) = 31900 J g^{-1}

82SUS

HEMLOCK, EASTERN; BARK; *Tsuga canadensis*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 1.6%; moisture content = 6.2%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

$q_v(\text{gross}) = 8802\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4890\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 20460\ \text{J g}^{-1}$

55CHA/MIT

HEMLOCK, WESTERN; *Tsuga heterophylla*; solid; air-dried at 105°-110°C (221°-230°F) density, 0.45 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.322$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.322$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 1.347$

gross heat of combustion: assume values refer to room temperature; air-dried.

$q_v(\text{gross}) = 8626\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4792\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 20050\ \text{J g}^{-1}$

12DUN; 68KAI/FRI; 66FRY

HEVEA (RUBBER TREE); solid; Material came from mature trees growing on Rengam series soils in Kuala Lumpur, Malaysia. Samples were oven-dried at 80°C (176°F) to constant weight, milled to a powder and pelleted in units of about 1 g each.

gross heat of combustion: dry weight basis, used 30 atm oxygen; assume values refer to room temperature.

branch bark

q_V(gross) = 7765 Btu lb^{-1}
q_V(gross) = 4314 cal g^{-1}
q_V(gross) = 18050 J g^{-1}

branch wood

q_V(gross) = 8037 ± 30.2 Btu lb^{-1}
q_V(gross) = 4465 ± 16.8 cal g^{-1}
q_V(gross) = 18682 ± 70.3 J g^{-1}

leaves

q_V(gross) = 9000 Btu lb^{-1}
q_V(gross) = 5000 cal g^{-1}
q_V(gross) = 20920 J g^{-1}

main-stem bark

q_V(gross) = 7675 Btu lb^{-1}
q_V(gross) = 4264 cal g^{-1}
q_V(gross) = 17841 J g^{-1}

main-stem wood

q_V(gross) = 7974 ± 30.2 Btu lb^{-1}
q_V(gross) = 4430 ± 16.8 cal g^{-1}
q_V(gross) = 18535± 70.3 J g^{-1}

petioles

q_V(gross) = 8377 Btu lb^{-1}
q_V(gross) = 4654 cal g^{-1}
q_V(gross) = 19472 J g^{-1}

trunk bark

q_V(gross) = 7875 Btu lb^{-1}
q_V(gross) = 4375 cal g^{-1}
q_V(gross) = 18305 J g^{-1}

trunk wood

q_V(gross) = 8062 ± 30.2 Btu lb^{-1}
q_V(gross) = 4479 ± 16.8 cal g^{-1}
q_V(gross) = 18740 ± 70.3 J g^{-1}

83LEO

HEVEA (RUBBER TREE), CLONE RRIM 527; solid; Material came from mature trees growing on Rengam series soils in Kuala Lumpur, Malaysia. Samples were oven-dried at 80°C (176°F) to constant weight, milled to a powder, and pelleted in units of about 1 g each.

gross heat of combustion: dry weight basis; used 30 atm oxygen; assume values refer to room temperature.

trunk and main-stem plant parts

q_V(gross) = 7897 Btu lb^{-1}
q_V(gross) = 4387 cal g^{-1}
q_V(gross) = 18355 J g^{-1}

leaves plus petioles plant parts

q_V(gross) = 8689 Btu lb^{-1}
q_V(gross) = 4827 cal g^{-1}
q_V(gross) = 20196 J g^{-1}

branches

q_V(gross) = 7870 Btu lb^{-1}
q_V(gross) = 4372 cal g^{-1}
q_V(gross) = 18292 J g^{-1}

83LEO

HEVEA (RUBBER TREE), CLONE RRIM 707; solid; Material came from mature trees growing on Rengam series soils in Kuala Lumpur, Malaysia. Samples were oven-dried at 80°C (176°F) to constant weight, milled to a powder, and pelleted in units of about 1 g each.

gross heat of combustion: dry weight basis; used 30 atm oxygen; assume values refer to room temperature.

trunk and main-stem plant parts	branches
q_v(gross) = 7987 Btu lb^{-1}	q_v(gross) = 7906 Btu lb^{-1}
q_v(gross) = 4437 cal g^{-1}	q_v(gross) = 4392 cal g^{-1}
q_v(gross) = 18564 J g^{-1}	q_v(gross) = 18376 J g^{-1}

leaves plus petioles plant parts

q_v(gross) = 9094 Btu lb^{-1}
q_v(gross) = 5052 cal g^{-1}
q_v(gross) = 21138 J g^{-1}

83LEO

HICKORY; genus *Carya*; solid.

gross heat of combustion: assume values refer to room temperature.

as received: 10.30% moisture	air-dried one hour at 105°C (221°F)
q_v(gross) = 7583 Btu lb^{-1}	q_v(gross) = 8455 Btu lb^{-1}
q_v(gross) = 4213 cal g^{-1}	q_v(gross) = 4697 cal g^{-1}
q_v(gross) = 17626 J g^{-1}	q_v(gross) = 19652 J g^{-1}

22PAR/DAV

HICKORY; *Carya spp.*; solid; Material was collected from the southern Atlantic and Gulf coastal plains in bottom-, swamp- and wet flat-land natural stand sites. Samples were dried at 70°C (158°F) to a constant weight; reported values were averaged over all positions of similar plant tissue for each tree and six trees per species were used.

gross heat of combustion: assume values refer to room temperature; values are on a dry weight basis.

bole wood

q_v(gross) = 8309 Btu lb^{-1}
q_v(gross) = 4616 cal g^{-1}
q_v(gross) = 19313 J g^{-1}

branch wood

q_v(gross) = 8122 Btu lb^{-1}
q_v(gross) = 4512 cal g^{-1}
q_v(gross) = 18878 J g^{-1}

bole bark

q_v(gross) = 7538 Btu lb^{-1}
q_v(gross) = 4188 cal g^{-1}
q_v(gross) = 17523 J g^{-1}

branch bark

q_v(gross) = 7565 Btu lb^{-1}
q_v(gross) = 4203 cal g^{-1}
q_v(gross) = 17595 J g^{-1}

foliage

q_v(gross) = 8237 Btu lb^{-1}
q_v(gross) = 4576 cal g^{-1}
q_v(gross) = 19146 J g^{-1}

82GOW/FRE

HORNBEAM; *Carpinus betulus*; solid; ultimate analysis: carbon, 48.99%; hydrogen, 6.20%; nitrogen, 0.06%; ash, 0.50%.

gross heat of combustion: 20°C (68°F), air-dried 110°-115°C (230°-240°F), ash free.

q_v(gross) = 8536 Btu lb^{-1}
q_v(gross) = 4742 cal g^{-1}
q_v(gross) = 19841 J g^{-1}

1883GOT

JUNIPER, UTAH; BARK; *Juniperus osteosperma*; solid; Bark was air-dried at room temperature. Composition is ash = 17.74% and char yield = 27.9%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel

q_v(gross) = 9260 Btu lb^{-1}
q_v(gross) = 5150 cal g^{-1}
q_v(gross) = 21530 J g^{-1}

char (from 500°C heating)

q_v(gross) = 13720 Btu lb^{-1}
q_v(gross) = 7620 cal g^{-1}
q_v(gross) = 31880 J g^{-1}

82SUS

JUNIPER, UTAH; FOLIAGE; *Juniperus osteosperma*; solid; freeze-dried to < 10% moisture content. Composition is ash = 4.22% and char yield = 24.5%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 10020 Btu lb^{-1}	q_v(gross) = 13160 Btu lb^{-1}
q_v(gross) = 5560 cal g^{-1}	q_v(gross) = 7310 cal g^{-1}
q_v(gross) = 23280 J g^{-1}	q_v(gross) = 30590 J g^{-1}

82SUS

JUNIPER, UTAH; STEMS; *Juniperus osteosperma*; solid; Stem samples were branches less than 0.25 in. diameter with foliage removed and freeze-dried to < 10% moisture content. Composition is ash = 6.05% and char yield = 26.2%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 8890 Btu lb^{-1}	q_v(gross) = 13310 Btu lb^{-1}
q_v(gross) = 4940 cal g^{-1}	q_v(gross) = 7390 cal g^{-1}
q_v(gross) = 20660 J g^{-1}	q_v(gross) = 30930 J g^{-1}

82SUS

LARCH; *Larix occidentalis*; solid; Wood was air-dried at room temperature. Composition is ash = 0.19% and char yield = 20.7%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 8530 Btu lb^{-1}	q_v(gross) = 13890 Btu lb^{-1}
q_v(gross) = 4740 cal g^{-1}	q_v(gross) = 7720 cal g^{-1}
q_v(gross) = 19830 J g^{-1}	q_v(gross) = 32290 J g^{-1}

82SUS

LARCH, BARK; ***Larix occidentalis***; solid; Bark samples were freeze-dried at room temperature. Composition is ash = 1.20% and char yield = 37.3%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 10250 Btu lb^{-1}	q_V(gross) = 13140 Btu lb^{-1}
q_V(gross) = 5690 cal g^{-1}	q_V(gross) = 7300 cal g^{-1}
q_V(gross) = 23820 J g^{-1}	q_V(gross) = 30540 J g^{-1}

82SUS

LARCH, LUMBER; ***Larix occidentalis***; solid; Wood was air-dried at room temperature. Composition is ash = 0.17% and char yield = 23.7%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 8700 Btu lb^{-1}	q_V(gross) = 13830 Btu lb^{-1}
q_V(gross) = 4830 cal g^{-1}	q_V(gross) = 7680 cal g^{-1}
q_V(gross) = 20220 J g^{-1}	q_V(gross) = 32150 J g^{-1}

82SUS

LARCH, WESTERN; BARK; ***Larix occidentalis***; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 1.6%; moisture content = 6.7%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

q_V(gross) = 8204 Btu lb^{-1}
q_V(gross) = 4558 cal g^{-1}
q_V(gross) = 19071 J g^{-1}

55CHA/MIT

LEAVES, TREE; RIPE HARDWOOD MIXTURE; solid; ultimate analysis: carbon, 52.15%; hydrogen, 6.11%; oxygen, 30.34%; nitrogen, 6.99%; sulfur, 0.16%; ash, 4.25%; proximate analysis as received: moisture, 9.97%; volatile matter, 66.92%; fixed carbon, 19.29%; ash, 3.82%.

gross heat of combustion: assume values refer to room temperature.

as received	dry basis
$q_V(\text{gross}) = 7990$ Btu lb^{-1}	$q_V(\text{gross}) = 8874$ Btu lb^{-1}
$q_V(\text{gross}) = 4439$ cal g^{-1}	$q_V(\text{gross}) = 4930$ cal g^{-1}
$q_V(\text{gross}) = 18571$ J g^{-1}	$q_V(\text{gross}) = 20629$ J g^{-1}

66KAI

LITTER FALL; solid; Material was collected for one year in a 79-year-old, low-altitude, New Zealand *Nothofagus solandri* variety forest. An even-aged stand of *Nothofagus* with a sparse subcanopy vegetation was chosen having the following percentage of ground covers (rejecting tree base points); litter or soil, 95.2%; bryophytes, 4.0%; exposed roots, 0.4%; and vascular plants, 0.4%. Throughfall was taken as suspended and dissolved material rainwashed from the plants, including material from rainfall, surface-washings from plants, and recretions from leaves.

gross heat of combustion: dry weight and assume values refer to room temperature.

branch material

$q_V(\text{gross}) = 8500$ Btu lb^{-1}
$q_V(\text{gross}) = 4700$ cal g^{-1}
$q_V(\text{gross}) = 19700$ J g^{-1}

floral material

$q_V(\text{gross}) = 8600$ Btu lb^{-1}
$q_V(\text{gross}) = 4800$ cal g^{-1}
$q_V(\text{gross}) = 20100$ J g^{-1}

samples with negligible amounts of throughfall

$q_V(\text{gross}) = 8600$ Btu lb^{-1}
$q_V(\text{gross}) = 4800$ cal g^{-1}
$q_V(\text{gross}) = 20100$ J g^{-1}

samples with intermediate amounts of throughfall

$q_V(\text{gross}) = 8300$ Btu lb^{-1}
$q_V(\text{gross}) = 4600$ cal g^{-1}
$q_V(\text{gross}) = 19200$ J g^{-1}

(more)

LITTER FALL - Continued

samples with large amounts of throughfall

q_v(gross) = 7700 Btu lb^{-1}
q_v(gross) = 4300 cal g^{-1}
q_v(gross) = 18000 J g^{-1}

72BAG

LOCUST, BLACK; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 80.94, ash content = 0.80, and fixed carbon = 18.26. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 50.73, hydrogen = 5.71, oxygen = 41.93, nitrogen = 0.57, sulfur = 0.01, chlorine = 0.08, and residue (ash) = 0.97.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8479 Btu lb^{-1}
q_v(gross) = 4711 cal g^{-1}
q_v(gross) = 19710 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7980 Btu lb^{-1}
q_v(net) = 4434 cal g^{-1}
q_v(net) = 18550 J g^{-1}

85JEN/EBE

MADRONE; *Arbutus menzeisii*; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 82.99, ash content = 0.57, and fixed carbon = 16.44. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 48.00, hydrogen = 5.96, oxygen = 44.95, nitrogen = 0.06, sulfur = 0.02, chlorine = 0.01, and residue (ash) = 1.00.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8350 Btu lb^{-1}
q_v(gross) = 4639 cal g^{-1}
q_v(gross) = 19410 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7830 Btu lb^{-1}
q_v(net) = 4350 cal g^{-1}
q_v(net) = 18200 J g^{-1}

85JEN/EBE

MAI CHAMPAH; *Michelia*; solid; from Thailand; air-dried at 105°-110°C (221°-230°F); density, 0.32 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} $°F^{-1}$) = 0.323
C_p(cal g^{-1} K^{-1}) = 0.323
C_p(J g^{-1} K^{-1}) = 1.351

12DUN

MANZANITA; *Arctostaphylos*; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 81.29, ash content = 0.82, and fixed carbon = 17.89. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 48.18, hydrogen = 5.94, oxygen = 44.68, nitrogen = 0.17, sulfur = 0.02, chlorine = 0.01, and residue (ash) = 1.00.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8303 Btu lb^{-1}
q_v(gross) = 4613 cal g^{-1}
q_v(gross) = 19300 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7783 Btu lb^{-1}
q_v(net) = 4324 cal g^{-1}
q_v(net) = 18090 J g^{-1}

85JEN/EBE

MANZANITA, GREENLEAF; FOLIAGE; *Arctostaphylos glandulosa*; solid; freeze-dried to < 10% moisture content. Composition is ash = 3.19% and char yield = 30.7%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 9350 Btu lb^{-1}	q_v(gross) = 13940 Btu lb^{-1}
q_v(gross) = 5190 cal g^{-1}	q_v(gross) = 7750 cal g^{-1}
q_v(gross) = 21730 J g^{-1}	q_v(gross) = 31410 J g^{-1}

82SUS

MAPLE; genus, *Acer*; solid; ultimate analysis: carbon, 50.40%; hydrogen, 5.90%; oxygen, 39.10%; nitrogen, 0.50%; sulfur, 0.0%; ash, 4.10%; proximate analysis as received in percent by weight: moisture, 0.0%; volatile matter, 76.1%; fixed carbon, 19.6%; ash, 4.3%.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 8195 Btu lb^{-1}
q_v(gross) = 4553 cal g^{-1}
q_v(gross) = 19050 J g^{-1}

68KAI/FRI; 66FRY

MAPLE, HEDGE; *Acer campestre*; solid; Material is a tree, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content was determined at 500°C (932°F) while the temperature was increased stepwise. Ash content of stem and branch wood = 1.2%; stem and branch bark = 9.7%; leaf = 10.3%; root = 10.0%.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
stem and branch wood (4 measurements)				
q_v(gross) =	8343	8440	30.1	Btu lb^{-1}
q_v(gross) =	4635	4689	16.7	cal g^{-1}
q_v(gross) =	19393	19619	69.9	J g^{-1}
stem and branch bark (5 measurements)				
q_v(gross) =	7607	8429	49.9	Btu lb^{-1}
q_v(gross) =	4226	4683	27.7	cal g^{-1}
q_v(gross) =	17682	19594	116	J g^{-1}
leaf (6 measurements)				
q_v(gross) =	7837	8732	5.4	Btu lb^{-1}
q_v(gross) =	4354	4851	3.0	cal g^{-1}
q_v(gross) =	18217	20297	13	J g^{-1}
root (4 measurements)				
q_v(gross) =	7879	8750	77.8	Btu lb^{-1}
q_v(gross) =	4377	4861	43.2	cal g^{-1}
q_v(gross) =	18313	20338	181	J g^{-1}

75PAP

MAPLE, RED; *Acer rubrum*; solid; mean age = 12.7 years, mean basal stem diameter = 7.8 cm, mean stem bark (proportion of dry weight) = 10.7%, ash content (proportion of oven dry weight) of components of sample: wood = 0.51%, branches = 1.4%, twigs = 2.1%, bark = 6.5%, and leaves = 5.2%.

gross heat of combustion: oven dry weight basis; assume values refer to room temperature.

wood:

q_v(gross) = 8654 Btu lb^{-1}
q_v(gross) = 4808 cal g^{-1}
q_v(gross) = 20117 J g^{-1}

bark:

q_v(gross) = 8203 Btu lb^{-1}
q_v(gross) = 4557 cal g^{-1}
q_v(gross) = 19066 J g^{-1}

branches:

q_v(gross) = 8568 Btu lb^{-1}
q_v(gross) = 4760 cal g^{-1}
q_v(gross) = 19916 J g^{-1}

twigs:

q_v(gross) = 8586 Btu lb^{-1}
q_v(gross) = 4770 cal g^{-1}
q_v(gross) = 19958 J g^{-1}

leaves:

q_v(gross) = 8957 Btu lb^{-1}
q_v(gross) = 4976 cal g^{-1}
q_v(gross) = 20820 J g^{-1}

79NEE/STE

MAPLE, RED; *Acer rubrum*; solid; Material came from various locations in New Hampshire. Bole samples were composed of cross sections taken from four positions along length of each tree (at the base, one-third, two-thirds, and at top of the stem). Branch samples were composed of cross sections taken from four positions along length of each of four branches (one branch from four positions in the live crown of the tree). Bark was removed from half of each bole and branch sample and all samples were oven-dried at 85°C (185°F) to a constant weight

gross heat of combustion: Assume values refer to room temperature, thermochemical calorie used and values were expressed on a dry matter basis and adjusted for heat of formation of nitric acid. All tests were made at 99% confidence level and numbers in parentheses are standard errors.

bole with bark

q_v(gross) = 8626 (25) Btu lb^{-1}
q_v(gross) = 4792 (14) cal g^{-1}
q_v(gross) = 20050 (59) J g^{-1}

bole without bark

q_v(gross) = 8737 (38) Btu lb^{-1}
q_v(gross) = 4854 (21) cal g^{-1}
q_v(gross) = 20309 (88) J g^{-1}

branch with bark

q_v(gross) = 8667 (47) Btu lb^{-1}
q_v(gross) = 4815 (26) cal g^{-1}
q_v(gross) = 20146 (109) J g^{-1}

branch without bark

q_v(gross) = 8734 (43) Btu lb^{-1}
q_v(gross) = 4852 (24) cal g^{-1}
q_v(gross) = 20301 (100) J g^{-1}

(more)

MAPLE, RED - Continued

foliage

q_V(gross) = 9119 Btu lb^{-1}
q_V(gross) = 5066 cal g^{-1}
q_V(gross) = 21196 J g^{-1}

81MUS/HOC

MAPLE, RED; *Acer rubrum*; solid; Material was collected from the southern Atlantic and Gulf coastal plains in bottom-, swamp- and wet flat-land natural stand sites. Samples were dried at 70°C (158°F) to a constant weight; reported values were averaged over all positions of similar plant tissue for each tree and six trees per species were used.

gross heat of combustion: assume values refer to room temperature; values are on a dry weight basis.

bole wood

q_V(gross) = 8437 Btu lb^{-1}
q_V(gross) = 4687 cal g^{-1}
q_V(gross) = 19610 J g^{-1}

bole bark

q_V(gross) = 7650 Btu lb^{-1}
q_V(gross) = 4250 cal g^{-1}
q_V(gross) = 17782 J g^{-1}

foliage

q_V(gross) = 8764 Btu lb^{-1}
q_V(gross) = 4869 cal g^{-1}
q_V(gross) = 20372 J g^{-1}

branch wood

q_V(gross) = 8345 Btu lb^{-1}
q_V(gross) = 4636 cal g^{-1}
q_V(gross) = 19397 J g^{-1}

branch bark

q_V(gross) = 8001 Btu lb^{-1}
q_V(gross) = 4445 cal g^{-1}
q_V(gross) = 18598 J g^{-1}

82GOW/FRE

MAPLE, SILVER; *Acer saccharinum*; solid; Each tree was separated into small parts (being less than 0.64 cm (1/4 in.) in diameter and roughly equivalent to tops and branches) and large parts with the weighted proportion of small (25%) and large (75%) material in the whole tree. Overall mean specific gravity for whole tree = 0.40 (oven dry weight and green volume). Bark proportion of whole tree = 19%.

gross heat of combustion: oven-dried, assume values refer to room temperature.

small parts

q_v(gross) = 8071 Btu lb^{-1}
q_v(gross) = 4484 cal g^{-1}
q_v(gross) = 18761 J g^{-1}

whole tree

q_v(gross) = 8023 Btu lb^{-1}
q_v(gross) = 4457 cal g^{-1}
q_v(gross) = 18648 J g^{-1}

large parts

q_v(gross) = 8006 Btu lb^{-1}
q_v(gross) = 4448 cal g^{-1}
q_v(gross) = 18610 J g^{-1}

81GEY

MAPLE, SUGAR; *Acer saccharum*; solid; air-dried at 105°-110°C (221°-230°F); density, 0.66 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} $°F^{-1}$) = 0.327
C_p(cal g^{-1} K^{-1}) = 0.327
C_p(J g^{-1} K^{-1}) = 1.368

12DUN

MAPLE, SUGAR; *Acer saccharum*; solid; Material came from various locations in New Hampshire. Bole samples were composed of cross sections taken from four positions along length of each tree (at the base, one-third, two-thirds, one at top of the stem). Branch samples were composed of cross sections taken from four positions along length of each of four branches (one branch from four positions in the live crown of the tree). Bark was removed from half of each bole and branch sample and all samples were oven-dried at 85°C (185°F) to a constant weight.

gross heat of combustion: Assume values refer to room temperature, thermochemical calorie used and values were expressed on a dry matter basis and adjusted for heat of formation of nitric acid. All tests were made at 99% confidence level and numbers in parentheses are standard errors.

bole with bark

q_V(gross) = 8705 (158) Btu lb^{-1}
q_V(gross) = 4836 (88) cal g^{-1}
q_V(gross) = 20234 (368) J g^{-1}

bole without bark

q_V(gross) = 8773 (52) Btu lb^{-1}
q_V(gross) = 4874 (29) cal g^{-1}
q_V(gross) = 20393 (121) J g^{-1}

foliage

q_V(gross) = 9020 Btu lb^{-1}
q_V(gross) = 5011 cal g^{-1}
q_V(gross) = 20966 J g^{-1}

branch with bark

q_V(gross) = 8771(184) Btu lb^{-1}
q_V(gross) = 4873 (102) cal g^{-1}
q_V(gross) = 20389 (427) J g^{-1}

branch without bark

q_V(gross) = 8863 (103) Btu lb^{-1}
q_V(gross) = 4924 (57) cal g^{-1}
q_V(gross) = 20602 (238) J g^{-1}

81MUS/HOC

MAPLE, SUGAR; BARK; *Acer saccharum*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 6.3%; moisture content = 6.0%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

q_V(gross) = 7301 Btu lb^{-1}
q_V(gross) = 4056 cal g^{-1}
q_V(gross) = 16970 J g^{-1}

55CHA/MIT

MAPLE, TATARIAN; *Acer tataricum*; solid; Material is a tree, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content was determined at 500°C (932°F) while the temperature was increased stepwise. Ash content of stem and branch wood = 0.6%; stem and branch bark = 7.5%; leaf = 5.61%; root = 5.8%.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
stem and branch wood (3 measurements)				
q_v(gross) =	8298	8341	52.9	Btu lb^{-1}
q_v(gross) =	4610	4634	29.4	cal g^{-1}
q_v(gross) =	19288	19389	123	J g^{-1}
stem and branch bark (5 measurements)				
q_v(gross) =	7970	8611	114	Btu lb^{-1}
q_v(gross) =	4428	4784	63.5	cal g^{-1}
q_v(gross) =	18527	20016	266	J g^{-1}
leaf (6 measurements)				
q_v(gross) =	8046	8525	110	Btu lb^{-1}
q_v(gross) =	4470	4736	61.2	cal g^{-1}
q_v(gross) =	18720	19815	256	J g^{-1}
root (3 measurements)				
q_v(gross) =	7754	8235	57.8	Btu lb^{-1}
q_v(gross) =	4308	4575	32.1	cal g^{-1}
q_v(gross) =	18025	19142	134	J g^{-1}

75PAP

OAK; ***Quercus pedunculata*****;** solid; ultimate analysis: carbon, 50.16%; hydrogen, 6.02%; nitrogen, 0.09%; ash, 0.37%.

gross heat of combustion: 20°C (68°F); air-dried at 110°-115°C (230°-240°F); ash free.

$q_v(\text{gross}) = 8296 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 4609 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 19284 \text{ J g}^{-1}$

species not identified; room temperature; air-dried one hour at 105°C (221°F).

$q_v(\text{gross}) \approx 8561 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 4756 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 19899 \text{ J g}^{-1}$

22PAR/DAV

OAK, BLACK; DEAD FOLIAGE; ***Quercus velutina*****;** The litter was air dried at room temperature. Composition is ash $\approx$ 3.46% and char yield $\approx$ 28.9%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
$q_v(\text{gross}) \approx 9150 \text{ Btu lb}^{-1}$	$q_v(\text{gross}) \approx 13290 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) \approx 5080 \text{ cal g}^{-1}$	$q_v(\text{gross}) \approx 7380 \text{ cal g}^{-1}$
$q_v(\text{gross}) \approx 21270 \text{ J g}^{-1}$	$q_v(\text{gross}) \approx 30880 \text{ J g}^{-1}$

82SUS

OAK, DURMAST; *Quercus petraea*; solid; Material is a tree, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content was determined at 500°C (932°F) while the temperature was increased stepwise. Ash content of trunk wood = 0.5%; branch wood = 1.0%; trunk bark = 10.4%; branch bark = 9.0%; twig = 3.7%; light-adapted leaf = 6.1%; shade-adapted leaf = 6.5%; acorns = 2.6%; root = 6.9%.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
trunk wood (4 measurements)				
q_V(gross) =	8545	8582	35.8	Btu lb^{-1}
q_V(gross) =	4747	4768	19.9	cal g^{-1}
q_V(gross) =	19861	19949	83.3	J g^{-1}
branch wood (3 measurements				
q_V(gross) =	8518	8620	38.0	Btu lb^{-1}
q_V(gross) =	4732	4789	21.1	cal g^{-1}
q_V(gross) =	19799	20037	88.3	J g^{-1}
trunk bark (4 measurements)				
q_V(gross) =	7997	8926	30.1	Btu lb^{-1}
q_V(gross) =	4443	4959	16.7	cal g^{-1}
q_V(gross) =	18590	20748	69.9	J g^{-1}
branch bark (4 measurements)				
q_V(gross) =	7675	8440	54.5	Btu lb^{-1}
q_V(gross) =	4264	4689	30.3	cal g^{-1}
q_V(gross) =	17841	19619	127	J g^{-1}
twig (4 measurements)				
q_V(gross) =	8363	8694	85.0	Btu lb^{-1}
q_V(gross) =	4646	4830	47.2	cal g^{-1}
q_V(gross) =	19439	20209	197	J g^{-1}
light-adapted leaf (5 measurements)				
q_V(gross) =	8698	9259	74.3	Btu lb^{-1}
q_V(gross) =	4832	5144	41.3	cal g^{-1}
q_V(gross) =	20217	21522	173	J g^{-1}

(more)

OAK, DURMAST - Continued

	dry weight basis	ash-free dry weight basis	std dev. of mean	
shade-adapted leaf (5 measurements)				
q_V(gross) =	8329	8905	59.0	Btu lb^{-1}
q_V(gross) =	4627	4947	32.8	cal g^{-1}
q_V(gross) =	19359	20698	137	J g^{-1}
acorns (3 measurements)				
q_V(gross) =	8377	8604	15	Btu lb^{-1}
q_V(gross) =	4654	4780	8.1	cal g^{-1}
q_V(gross) =	19472	20000	34	J g^{-1}
root (3 measurements)				
q_V(gross) =	8089	8692	47.7	Btu lb^{-1}
q_V(gross) =	4494	4829	26.5	cal g^{-1}
q_V(gross) =	18803	20205	111	J g^{-1}

75PAP

OAK, NORTHERN RED; *Quercus rubra*; solid; Material was extractive-free wood (EFW) comprising cellulose, 42.86%; hemicellulose, 33.33%; and lignin, 23.81%. The relationship between gross heat of combustion and moisture content (MC) is given by: $\ell n q_V(\text{Btu lb}^{-1}) = 9.0389-(0.0107)\text{MC}(\%)$ for EFW.

gross heat of combustion: oven-dry basis, assume values refer to room temperature; values are reported in international British thermal units per pound and converted below into thermochemical units.

q_V(gross) = 8581 Btu lb^{-1}
q_V(gross) = 4767 cal g^{-1}
q_V(gross) = 19945 J g^{-1}

78MUR/MAS

OAK, NORTHERN RED; BARK; *Quercus rubra*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 5.4%; moisture content = 4.4%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

q_V(gross) = 8030 Btu lb^{-1}
q_V(gross) = 4461 cal g^{-1}
q_V(gross) = 18665 J g^{-1}

55CHA/MIT

OAK, RED; *Quercus rubra*; solid; air-dried at 105°-110°C (221°-230°F), density, 0.62 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} °F^{-1}) = 0.331
C_p(cal g^{-1} K^{-1}) = 0.331
C_p(J g^{-1} K^{-1}) = 1.385

12DUN

OAK, RED; *Quercus rubra*; solid; Material came from various locations in New Hampshire. Bole samples were composed of cross sections taken from four positions along length of each tree (at the base, one-third, two-thirds, and at top of the stem). Branch samples were composed of cross sections taken from four positions along length of each of four branches (one branch from four positions in the live crown of the tree). Bark was removed from half of each bole and branch sample and all samples were oven-dried at 85°C (185°F) to a constant weight.

gross heat of combustion: Assume values refer to room temperature, thermochemical calorie used and values were expressed on a dry matter basis and adjusted for heat of formation of nitric acid. All tests were made at 99% confidence level and numbers in parentheses are standard errors.

bole with bark

q_v(gross) = 8780 (45) Btu lb^{-1}
q_v(gross) = 4878 (25) cal g^{-1}
q_v(gross) = 20410 (105) J g^{-1}

bole without bark

q_v(gross) = 8654 (45) Btu lb^{-1}
q_v(gross) = 4808 (25) cal g^{-1}
q_v(gross) = 20117 (105) J g^{-1}

foliage

q_v(gross) = 8941 Btu lb^{-1}
q_v(gross) = 4967 cal g^{-1}
q_v(gross) = 20782 J g^{-1}

branch with bark

q_v(gross) = 8797 (56) Btu lb^{-1}
q_v(gross) = 4887 (31) cal g^{-1}
q_v(gross) = 20447 (130) J g^{-1}

branch without bark

q_v(gross) = 8654 (56) Btu lb^{-1}
q_v(gross) = 4808 (31) cal g^{-1}
q_v(gross) = 20117 (130) J g^{-1}

81MUS/HOC

OAK, TAN; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 80.93, ash content = 1.67, and fixed carbon = 17.40. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 47.81, hydrogen = 5.93, oxygen = 44.12, nitrogen = 0.12, sulfur = 0.01, chlorine = 0.01, and residue (ash) = 2.00.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8144 Btu lb^{-1}
q_v(gross) = 4524 cal g^{-1}
q_v(gross) = 18930 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 7628 Btu lb^{-1}
q_v(net) = 4238 cal g^{-1}
q_v(net) = 17730 J g^{-1}

85JEN/EBE

OAK, TAN; BARK; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 73.11, ash content = 3.49, and fixed carbon = 23.40.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 7916 Btu lb^{-1}
q_v(gross) = 4398 cal g^{-1}
q_v(gross) = 18400 J g^{-1}

85JEN/EBE

OAK, TAN; SAPWOOD; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 83.61, ash content = 1.03, and fixed carbon = 15.36.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8204 Btu lb^{-1}
q_v(gross) = 4558 cal g^{-1}
q_v(gross) = 19070 J g^{-1}

85JEN/EBE

OAK, TURKEY; *Quercus cerris*; solid; Material is a tree, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content was determined at 500°C (932°F) while the temperature was increased stepwise. Ash content of trunk wood = 1.1%; trunk bark = 8.4%; branch wood = 1.3%; branch bark = 8.3%; twig = 5.3%; light-adapted leaf = 5.4%; shade-adapted leaf = 6.2%; acorns = 2.1%; root = 4.6%.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
trunk wood (3 measurements)				
q_V(gross) =	8523	8617	30.4	Btu lb^{-1}
q_V(gross) =	4735	4787	16.9	cal g^{-1}
q_V(gross) =	19811	20029	70.7	J g^{-1}
trunk bark (7 measurements)				
q_V(gross) =	8386	9146	43.2	Btu lb^{-1}
q_V(gross) =	4659	5081	24.0	cal g^{-1}
q_V(gross) =	19493	21259	100	J g^{-1}
branch wood (3 measurements)				
q_V(gross) =	8395	8510	57.1	Btu lb^{-1}
q_V(gross) =	4664	4728	31.7	cal g^{-1}
q_V(gross) =	19514	19782	133	J g^{-1}
branch bark (4 measurements)				
q_V(gross) =	7708	8404	43.2	Btu lb^{-1}
q_V(gross) =	4282	4669	24.0	cal g^{-1}
q_V(gross) =	17916	19535	100	J g^{-1}
twig (4 measurements)				
q_V(gross) =	8332	8807	99.2	Btu lb^{-1}
q_V(gross) =	4629	4893	55.1	cal g^{-1}
q_V(gross) =	19368	20472	231	J g^{-1}
light-adapted leaf (5 measurements)				
q_V(gross) =	8901	9412	41.2	Btu lb^{-1}
q_V(gross) =	4945	5229	22.9	cal g^{-1}
q_V(gross) =	20690	21878	95.8	J g^{-1}

(more)

OAK, TURKEY - Continued

	dry weight basis	ash-free dry weight basis	std dev. of mean	
shade-adapted leaf (5 measurements)				
q_V(gross) =	8653	9227	48.6	Btu lb^{-1}
q_V(gross) =	4807	5126	27.0	cal g^{-1}
q_V(gross) =	20112	21447	113	J g^{-1}
acorns (3 measurements)				
q_V(gross) =	8118	8289	15	Btu lb^{-1}
q_V(gross) =	4510	4605	8.1	cal g^{-1}
q_V(gross) =	18870	19267	34	J g^{-1}
root (3 measurements)				
q_V(gross) =	8233	8627	34.7	Btu lb^{-1}
q_V(gross) =	4574	4793	19.3	cal g^{-1}
q_V(gross) =	19138	20054	80.7	J g^{-1}

75PAP

OAK, WATER; *Quercus nigra*; solid; mean age = 11.3 years, mean basal stem diameter = 9.8 cm, mean stem bark (proportion of dry weight) = 14.8%, ash content 1.7%, twigs = 2.6%, bark = 6.1%, and leaves = 3.3%.

gross heat of combustion: oven dry weight basis; assume values refer to room temperature.

wood:

q_V(gross) = 8599 Btu lb^{-1}
q_V(gross) = 4777 cal g^{-1}
q_V(gross) = 19987 J g^{-1}

bark:

q_V(gross) = 8320 Btu lb^{-1}
q_V(gross) = 4622 cal g^{-1}
q_V(gross) = 19338 J g^{-1}

branches:

q_V(gross) = 8561 Btu lb^{-1}
q_V(gross) = 4756 cal g^{-1}
q_V(gross) = 19899 J g^{-1}

twigs:

q_V(gross) = 8672 Btu lb^{-1}
q_V(gross) = 4818 cal g^{-1}
q_V(gross) = 20159 J g^{-1}

leaves:

q_V(gross) = 9151 Btu lb^{-1}
q_V(gross) = 5084 cal g^{-1}
q_V(gross) = 21271 J g^{-1}

79NEE/STE

OAK, WATER; ***Quercus nigra***; solid; Material was collected from the southern Atlantic and Gulf coastal plains in bottom-, swamp- and wet flat-land natural stand sites. Samples were dried at 70°C (158°F) to a constant weight; reported values were averaged over all positions of similar plant tissue for each tree and six trees per species were used.

gross heat of combustion: assume values refer to room temperature; values are on a dry weight basis.

bole wood

q_v(gross) = 8289 Btu lb^{-1}
q_v(gross) = 4605 cal g^{-1}
q_v(gross) = 19267 J g^{-1}

bole bark

q_v(gross) = 8393 Btu lb^{-1}
q_v(gross) = 4663 cal g^{-1}
q_v(gross) = 19510 J g^{-1}

foliage

q_v(gross) = 8581 Btu lb^{-1}
q_v(gross) = 4767 cal g^{-1}
q_v(gross) = 19945 J g^{-1}

branch wood

q_v(gross) = 8237 Btu lb^{-1}
q_v(gross) = 4576 cal g^{-1}
q_v(gross) = 19146 J g^{-1}

branch bark

q_v(gross) = 8318 Btu lb^{-1}
q_v(gross) = 4621 cal g^{-1}
q_v(gross) = 19334 J g^{-1}

82GOW/FRE

OAK, WHITE; ***Quercus alba***; solid; air-dried at 105°-110°C (221°-230°F), density, 0.78 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} °F^{-1}) = 0.325
C_p(cal g^{-1} K^{-1}) = 0.325
C_p(J g^{-1} K^{-1}) = 1.360

12DUN

OAK, WHITE; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 81.28, ash content = 1.52, and fixed carbon = 17.20. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 49.48, hydrogen = 5.38, oxygen = 43.13, nitrogen = 0.35, sulfur = 0.01, chlorine = 0.04, and residue (ash) = 1.61.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_V(gross) = 8355 Btu lb^{-1}
q_V(gross) = 4641 cal g^{-1}
q_V(gross) = 19420 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_V(net) = 7886 Btu lb^{-1}
q_V(net) = 4381 cal g^{-1}
q_V(net) = 18330 J g^{-1}

85JEN/EBE

OAK, WHITE; BARK; *Quercus alba*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 10.7%; moisture content = 6.5%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

q_V(gross) = 6995 Btu lb^{-1}
q_V(gross) = 3886 cal g^{-1}
q_V(gross) = 16259 J g^{-1}

55CHA/MIT

PINE, EASTERN WHITE; *Pinus strobus*; solid; Material came from various locations in New Hampshire. Bole samples were composed of cross sections taken from four positions along length of each tree (at the base, one-third, two-thirds, one at top of the stem). Branch samples were composed of cross sections taken from four positions along length of each of four branches (one branch from four positions in the live crown of the tree). Bark was removed from half of each bole and branch sample and all samples were oven-dried at 85°C (185°F) to a constant weight.

gross heat of combustion: Assume values refer to room temperature, thermochemical calorie used and values were expressed on a dry matter basis and adjusted for heat of formation of nitric acid. All tests were made at 99% confidence level and numbers in parentheses are standard errors.

bole with bark

q_v(gross) = 9049 (59) Btu lb^{-1}
q_v(gross) = 5027 (33) cal g^{-1}
q_v(gross) = 21033 (138) J g^{-1}

bole without bark

q_v(gross) = 9031 (58) Btu lb^{-1}
q_v(gross) = 5017 (32) cal g^{-1}
q_v(gross) = 20991 (134) J g^{-1}

foliage

q_v(gross) = 9407 Btu lb^{-1}
q_v(gross) = 5226 cal g^{-1}
q_v(gross) = 21866 J g^{-1}

branch with bark

q_v(gross) = 9679 (56) Btu lb^{-1}
q_v(gross) = 5377 (31) cal g^{-1}
q_v(gross) = 22497 (130) J g^{-1}

branch without bark

q_v(gross) = 9182 (49) Btu lb^{-1}
q_v(gross) = 5101 (27) cal g^{-1}
q_v(gross) = 21343 (113) J g^{-1}

81MUS/HOC

PINE, JACK; BARK; *Pinus banksiana*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 1.7%; moisture content = 6.6%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

q_v(gross) = 8761 Btu lb^{-1}
q_v(gross) = 4867 cal g^{-1}
q_v(gross) = 20364 J g^{-1}

55CHA/MIT

PINE LITTER, DUFF; solid; Material is partially decomposed pine litter called the "F" layer air-dried at room temperature. Composition is ash = 31.91% and char yield = 38.8%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 10010 Btu lb^{-1}	q_v(gross) = 13530 Btu lb^{-1}
q_v(gross) = 5560 cal g^{-1}	q_v(gross) = 7520 cal g^{-1}
q_v(gross) = 23260 J g^{-1}	q_v(gross) = 31450 J g^{-1}

82SUS

PINE, LOBLOLLY; *Pinus taeda*; solid; unextracted specific gravity, 0.49 (oven dry weight and green volume).

specific heat: 333-413 K (140°-284°F); samples were oven-dried at 100°C (212°F) for 12 hours before measurements were made.

C_p(Btu lb^{-1} °F^{-1}) = $0.25406 + 5.2761 \times 10^{-4}$ T
C_p(cal g^{-1} K^{-1}) = $0.01153 + 9.497 \times 10^{-4}$ T
C_p(J g^{-1} K^{-1}) = $0.04824 + 3.9735 \times 10^{-3}$ T

69McM

PINE, LOBLOLLY; EXTRACTIVES; *Pinus taeda*; solid; residue obtained from alcohol-benzene extraction of loblolly pine wood; mean extractive content, 6.08% [68McM].

specific heat: 333-413 K (140°-284°F); samples were oven-dried at 100°C (212°F) for 12 hours before measurements were made.

C_p(Btu lb^{-1} °F^{-1}) = $0.34781 + 6.06 \times 10^{-4}$ T
C_p(cal g^{-1} K^{-1}) = $0.06945 + 1.09 \times 10^{-3}$ T
C_p(J g^{-1} K^{-1}) = $0.29058 + 4.56 \times 10^{-3}$ T

70McM

PINE, LODGEPOLE; BARK; *Pinus contorta*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 2.0%; moisture content = 5.6%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

q_v(gross) = 10190 Btu lb^{-1}
q_v(gross) = 5661 cal g^{-1}
q_v(gross) = 23686 J g^{-1}

55CHA/MIT

PINE, LODGEPOLE; FOLIAGE; ***Pinus contorta***; solid; freeze-dried to < 10% moisture content. Composition is ash = 2.21% and char yield = 29.2%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
$q_v(\text{gross}) = 9530\ \text{Btu lb}^{-1}$	$q_v(\text{gross}) = 13810\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 5290\ \text{cal g}^{-1}$	$q_v(\text{gross}) = 7670\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 22140\ \text{J g}^{-1}$	$q_v(\text{gross}) = 32110\ \text{J g}^{-1}$

82SUS

PINE, LODGEPOLE; NEEDLES; ***Pinus contorta***; solid; Samples were taken at mid-crown position, in May and November, at 6300 and 5700 feet altitude, and from young and old trees. Crude protein levels averaged 4.52% of air-dry weight. Material was frozen and subsequently dried or preserved in 70% alcohol and then dried.

gross heat of combustion: air-dried weight, assume values refer to room temperature.

$q_v(\text{gross}) = 8951\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4973\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 20807\ \text{J g}^{-1}$

68BOA/KIC

PINE, LONGLEAF; ***Pinus palustris***; solid; air-dried at 105°-110°C (221°-230°F), density, 0.68 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.337$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.337$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 1.410$

12DUN

PINE, PINYON; FOLIAGE; ***Pinus edulis***; solid; freeze dried to < 10% moisture content. Composition is ash = 3.22% and char yield = 26.7%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
$q_v(\text{gross}) = 9470\ \text{Btu lb}^{-1}$	$q_v(\text{gross}) = 13510\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 5260\ \text{cal g}^{-1}$	$q_v(\text{gross}) = 7510\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 22020\ \text{J g}^{-1}$	$q_v(\text{gross}) = 31400\ \text{J g}^{-1}$

82SUS

PINE, PINYON; STEMS; ***Pinus edulis***; solid; Stem samples were branches < 0.25 in. diameter with foliage removed and freeze-dried to < 10% moisture content. Composition is ash = 2.23% and char yield = 22.3%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 9630 Btu lb^{-1}	q_v(gross) = 13940 Btu lb^{-1}
q_v(gross) = 5350 cal g^{-1}	q_v(gross) = 7740 cal g^{-1}
q_v(gross) = 22390 J g^{-1}	q_v(gross) = 32400 J g^{-1}

82SUS

PINE, PONDEROSA; ***Pinus ponderosa***; solid; Samples were conditioned to moisture equilibrium at 27°C (80°F) and 30% relative humidity; moisture content of wood ~6%.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 8327 ± 68 Btu lb^{-1}
q_v(gross) = 4626 ± 38 cal g^{-1}
q_v(gross) = 19355 ± 159 J g^{-1}

67ROB; 64BRO

PINE, PONDEROSA; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 82.54, ash content = 0.29, and fixed carbon = 17.17. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 49.25, hydrogen = 5.99, oxygen = 44.36, nitrogen = 0.06, sulfur = 0.03, chlorine = 0.01, and residue (ash) = 0.30.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8613 Btu lb^{-1}
q_v(gross) = 4785 cal g^{-1}
q_v(gross) = 20020 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 8088 Btu lb^{-1}
q_v(net) = 4493 cal g^{-1}
q_v(net) = 18800 J g^{-1}

85JEN/EBE

PINE, PONDEROSA; ***Pinus ponderosa*****;** solid; Wood was air-dried at room temperature. Composition is ash = 0.33% and char yield = 19.5%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 8960 Btu lb^{-1}	q_v(gross) = 14130 Btu lb^{-1}
q_v(gross) = 4980 cal g^{-1}	q_v(gross) = 7850 cal g^{-1}
q_v(gross) = 20820 J g^{-1}	q_v(gross) = 32850 J g^{-1}

82SUS

PINE, PONDEROSA; ***Pinus ponderosa*****;** solid; Material was obtained from Whitaker's Forest in Tulare County, California, with predominant soil series of Shaver sandy loam derived from granitic parent material. The layer was collected from the understory of the forest floor. Average yearly decomposition of the forest floor for ponderosa pine is: litter, 11.16%; duff, 2.80%.

gross heat of combustion: assume values refer to room temperature; ash-free.

branch-twig	litter
q_v(gross) = 9029 Btu lb^{-1}	q_v(gross) = 9283 Btu lb^{-1}
q_v(gross) = 5016 cal g^{-1}	q_v(gross) = 5157 cal g^{-1}
q_v(gross) = 20987 J g^{-1}	q_v(gross) = 21577 J g^{-1}

duff

q_v(gross) = 10240 Btu lb^{-1}
q_v(gross) = 5689 cal g^{-1}
q_v(gross) = 23803 J g^{-1}

78AGE/WAK

PINE, PONDEROSA; AZ 78 FOLIAGE; ***Pinus ponderosa*****;** solid; freeze-dried to < 10% moisture content. Composition is ash = 2.39% and char yield = 25.2%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 9470 Btu lb^{-1}	q_v(gross) = 13990 Btu lb^{-1}
q_v(gross) = 5260 cal g^{-1}	q_v(gross) = 7770 cal g^{-1}
q_v(gross) = 22010 J g^{-1}	q_v(gross) = 32510 J g^{-1}

82SUS

PINE, PONDEROSA; BARK; ***Pinus ponderosa*****;** solid; Bark samples were air-dried at room temperature. Composition is ash = 0.52% and char yield = 46.9%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 9470 Btu lb^{-1}	q_V(gross) = 13110 Btu lb^{-1}
q_V(gross) = 5260 cal g^{-1}	q_V(gross) = 7280 cal g^{-1}
q_V(gross) = 22010 J g^{-1}	q_V(gross) = 30470 J g^{-1}

82SUS

PINE, PONDEROSA; CA 77 FOLIAGE; ***Pinus ponderosa*****;** solid; freeze-dried to < 10% moisture content. Composition is ash = 2.63% and char yield = 29.4%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 8840 Btu lb^{-1}	q_V(gross) = 14190 Btu lb^{-1}
q_V(gross) = 4910 cal g^{-1}	q_V(gross) = 7880 cal g^{-1}
q_V(gross) = 20550 J g^{-1}	q_V(gross) = 32980 J g^{-1}

82SUS

PINE, PONDEROSA; DEAD FOLIAGE; ***Pinus ponderosa*****;** solid; The litter was air-dried at room temperature. Composition is ash = 3.75% and char yield = 26.5%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 9860 Btu lb^{-1}	q_V(gross) = 13740 Btu lb^{-1}
q_V(gross) = 5480 cal g^{-1}	q_V(gross) = 7630 cal g^{-1}
q_V(gross) = 22910 J g^{-1}	q_V(gross) = 31940 J g^{-1}

82SUS

PINE, PONDEROSA; HEARTWOOD LUMBER; ***Pinus ponderosa*****;** solid; Lumber was air-dried at room temperature. Composition is ash = 0.24% and char yield = 20.3%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 9020 Btu lb^{-1}	q_V(gross) = 14120 Btu lb^{-1}
q_V(gross) = 5010 cal g^{-1}	q_V(gross) = 7840 cal g^{-1}
q_V(gross) = 20970 J g^{-1}	q_V(gross) = 32820 J g^{-1}

82SUS

PINE, PONDEROSA; MT 77 FOLIAGE; ***Pinus ponderosa*****;** solid; freeze-dried to < 10% moisture content. Composition is ash = 2.94% and char yield = 29.0%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 9640 Btu lb^{-1}	q_V(gross) = 14030 Btu lb^{-1}
q_V(gross) = 5350 cal g^{-1}	q_V(gross) = 7790 cal g^{-1}
q_V(gross) = 22400 J g^{-1}	q_V(gross) = 32600 J g^{-1}

82SUS

PINE, PONDEROSA; MT 78 FOLIAGE; ***Pinus ponderosa*****;** solid; freeze-dried to < 10% moisture content. Composition is ash = 2.61% and char yield = 26.9%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 9580 Btu lb^{-1}	q_V(gross) = 13990 Btu lb^{-1}
q_V(gross) = 5320cal g^{-1}	q_V(gross) = 7770 cal g^{-1}
q_V(gross) = 22270 J g^{-1}	q_V(gross) = 32510 J g^{-1}

82SUS

PINE, SLASH; BARK; ***Pinus elliottii*****;** solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 0.6%; moisture content = 6.4%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

q_v(gross) = 9002 Btu lb^{-1}
q_v(gross) = 5001 cal g^{-1}
q_v(gross) = 20924 J g^{-1}

55CHA/MIT

PINE, SLASH; FOLIAGE; ***Pinus elliottii*****;** solid; freeze-dried to < 10% moisture content. Composition is ash □ 1.54% and char yield = 29.5%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 9300 Btu lb^{-1}	q_v(gross) = 13640 Btu lb^{-1}
q_v(gross) = 5170 cal g^{-1}	q_v(gross) = 7580 cal g^{-1}
q_v(gross) = 21610 J g^{-1}	q_v(gross) = 31700 J g^{-1}

82SUS

PINE, SUGAR; ***Pinus lambertiana*****;** solid; Material was obtained from Whitaker's Forest in Tulare County, California, with predominant soil series of Shaver sandy loam derived from granitic parent material. The layer was collected from the understory of the forest floor. Average yearly decomposition of the forest floor for sugar pine is: litter, 8.60%; duff, 2.56%.

gross heat of combustion: assume values refer to room temperature; ash free.

branch-twig	litter
q_v(gross) □ 9220 Btu lb^{-1}	q_v(gross) = 9268 Btu lb^{-1}
q_v(gross) = 5122 cal g^{-1}	q_v(gross) □ 5249 cal g^{-1}
q_v(gross) = 21430 J g^{-1}	q_v(gross) = 21543 J g^{-1}

duff

q_v(gross) □ 9365 Btu lb^{-1}
q_v(gross) □ 5203 cal g^{-1}
q_v(gross) □ 21769 J g^{-1}

78AGE/WAK

PINE, WESTERN WHITE; DEAD FOLIAGE; *Pinus monticola*; solid; The litter was air-dried at room temperature. Composition is ash = 3.53% and char yield = 34.0%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_v(gross) = 9360 Btu lb^{-1}	q_v(gross) □ 13370 Btu lb^{-1}
q_v(gross) □ 5200 cal g^{-1}	q_v(gross) = 7430 cal g^{-1}
q_v(gross) = 21760 J g^{-1}	q_v(gross) = 31080 J g^{-1}

82SUS

PINE, WHITE; *Pinus strobus*; solid; air-dried at 105°-110°C (221°-230°F); density, 0.25 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} °F^{-1}) = 0.331
C_p(cal g^{-1} K^{-1}) = 0.331
C_p(J g^{-1} K^{-1}) = 1.385

12DUN

PINE, WHITE; SAWDUST; *Pinus strobus*; proximate analysis, as delivered: moisture, 7.0%; volatile matter, 78.76%; fixed carbon, 14.10%; ash, 0.14%.

gross heat of combustion: air-dried; assume values refer to room temperature.

q_v(gross) = 8266 Btu lb^{-1}
q_v(gross) = 4592 cal g^{-1}
q_v(gross) = 19213 J g^{-1}

68KAI/FRI; 66FRY

POPLAR; genus *Populus*; solid.

gross heat of combustion: assume values refer to room temperature.

as received: 10.69% moisture	air-dried one hour at 105°C (221°F)
q_v(gross) = 7722 Btu lb^{-1}	q_v(gross) = 8645 Btu lb^{-1}
q_v(gross) = 4290 cal g^{-1}	q_v(gross) = 4803 cal g^{-1}
q_v(gross) = 17948 J g^{-1}	q_v(gross) = 20096 J g^{-1}

22PAR/DAV

POPLAR; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 82.32, ash content = 1.33, and fixed carbon = 16.35. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 48.45, hydrogen = 5.85, oxygen = 43.69, nitrogen = 0.47, sulfur = 0.01, chlorine = 0.10, and residue (ash) = 1.43.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

$q_v(\text{gross}) = 8337\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4632\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19380\ \text{J g}^{-1}$

net heat of combustion: assume values refer to room temperature.

$q_v(\text{net}) = 7826\ \text{Btu lb}^{-1}$
$q_v(\text{net}) = 4348\ \text{cal g}^{-1}$
$q_v(\text{net}) = 18190\ \text{J g}^{-1}$

85JEN/EBE

POPLAR, YELLOW; *Liriodendron tulipifera*; solid; mean age = 14 years, mean basal stem diameter = 9.7 cm, mean stem bark (proportion of dry weight) = 20.4%, ash content (proportion of oven dry weight) of components of sample: wood = 0.63%, branches = 1.4%, twigs = 2.4%, bark = 4.3%, and leaves = 5.2%.

gross heat of combustion: oven-dry weight basis; assume values refer to room temperature.

wood:

$q_v(\text{gross}) = 8674\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4819\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 20162\ \text{J g}^{-1}$

twigs:

$q_v(\text{gross}) = 8608\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4782\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 20008\ \text{J g}^{-1}$

bark:

$q_v(\text{gross}) = 8336\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4631\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19376\ \text{J g}^{-1}$

leaves:

$q_v(\text{gross}) = 9121\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 5067\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 21200\ \text{J g}^{-1}$

branches:

$q_v(\text{gross}) = 8640\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4800\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 20083\ \text{J g}^{-1}$

79NEE/STE

POPULUS HYBRIDS; solid; Sample specimens were composite wood/bark from 4-year-old trees of seven hybrids. Average ash content is 0.80% of oven-dry weight. Selected nutrients given in percent of oven-dry weight are phosphorus, 0.08; potassium, 0.35; calcium, 0.59; magnesium, 0.06; and total extractives, 12.2. Holocellulose and pentosan are 67.1% and 16.2% extractive free oven-dry weight, respectively.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 8386 Btu lb^{-1}
q_V(gross) = 4659 cal g^{-1}
q_V(gross) = 19493 J g^{-1}

79BOW/BLA

REDBUD; *Cercis canadensis*; solid; mean age = 10.3 years, mean basal stem diameter = 6.5 cm, mean stem bark (proportion of dry weight) = 9.2%, ash content (proportion of oven dry weight) of components of sample: wood = 0.96%, branches = 1.5%, twigs = 2.2%, bark = 5.5%, and leaves = 5.6%.

gross heat of combustion: oven dry weight basis; assume values refer to room temperature.

wood:

q_V(gross) = 8755 Btu lb^{-1}
q_V(gross) = 4864 cal g^{-1}
q_V(gross) = 20351 J g^{-1}

bark:

q_V(gross) = 8336 Btu lb^{-1}
q_V(gross) = 4631 cal g^{-1}
q_V(gross) = 19376 J g^{-1}

branches:

q_V(gross) = 8528 Btu lb^{-1}
q_V(gross) = 4738 cal g^{-1}
q_V(gross) = 19824 J g^{-1}

twigs:

q_V(gross) = 8525 Btu lb^{-1}
q_V(gross) = 4736 cal g^{-1}
q_V(gross) = 19815 J g^{-1}

leaves:

q_V(gross) = 9158 Btu lb^{-1}
q_V(gross) = 5088 cal g^{-1}
q_V(gross) = 21288 J g^{-1}

79NEE/STE

REDWOOD; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 79.72, ash content = 0.36, and fixed carbon = 19.92. Also the ultimate analysis of the elemental composition of the fuel (values in percent by weight dry basis) is carbon = 50.64, hydrogen = 5.98, oxygen = 42.88, nitrogen = 0.05, sulfur = 0.03, chlorine = 0.02, and residue (ash) = 0.40.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8914 Btu lb^{-1}
q_v(gross) = 4952 cal g^{-1}
q_v(gross) = 20720 J g^{-1}

net heat of combustion: assume values refer to room temperature.

q_v(net) = 8393 Btu lb^{-1}
q_v(net) = 4663 cal g^{-1}
q_v(net) = 19510 J g^{-1}

85JEN/EBE

REDWOOD, BARK; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 68.44, ash content = 1.60, and fixed carbon = 29.96.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8424 Btu lb^{-1}
q_v(gross) = 4680 cal g^{-1}
q_v(gross) = 19580 J g^{-1}

85JEN/EBE

REDWOOD, HEARTWOOD; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 80.28, ash content = 0.17, and fixed carbon = 19.55.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 9095 Btu lb^{-1}
q_v(gross) = 5053 cal g^{-1}
q_v(gross) = 21140 J g^{-1}

85JEN/EBE

REDWOOD, MILL WASTES; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 81.19, ash content = 0.18, and fixed carbon = 18.63.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 9026 Btu lb^{-1}
q_v(gross) = 5014 cal g^{-1}
q_v(gross) = 20980 J g^{-1}

85JEN/EBE

REDWOOD, SAPWOOD; solid; Material is considered biomass fuel and has proximate analysis values (in percent by weight dry basis) for volatile concentration (VCM) = 80.12, ash content = 0.67, and fixed carbon = 19.21.

gross heat of combustion: assume values refer to room temperature; determination performed at 30 atm O_2, and corrections applied for the formation of nitric and sulfuric acids.

q_v(gross) = 8738 Btu lb^{-1}
q_v(gross) = 4854 cal g^{-1}
q_v(gross) = 20310 J g^{-1}

85JEN/EBE

SEQUOIA, GIANT; *Sequoiadendron giganteum*; solid; Material was obtained from Whitaker's Forest in Tulare County, California, with predominant soil series of Shaver sandy loam derived from granitic parent material. The layer was collected from the understory of the forest floor. Average yearly decomposition of the forest floor for giant sequoia is: litter, 2.77%; duff, 11.40%.

gross heat of combustion: assume values refer to room temperature; ash-free.

branch-twig

q_v(gross) = 8885 Btu lb^{-1}
q_v(gross) = 4936 cal g^{-1}
q_v(gross) = 20652 J g^{-1}

litter

q_v(gross) = 9196 Btu lb^{-1}
q_v(gross) = 5109 cal g^{-1}
q_v(gross) = 21376 J g^{-1}

duff

q_v(gross) = 9225 Btu lb^{-1}
q_v(gross) = 5123 cal g^{-1}
q_v(gross) = 21435 J g^{-1}

78AGE/WAK

SOUTHERN HARDWOOD, SAWMILL RESIDUE, FRESH; solid; Material is mixed sawdust and bark residue coming directly from the mill (generated the same day) collected from 6 mills around Baton Rouge, Louisiana. The average moisture content is 107%; when moderately packed the average density ≈ 24.0 lb green wt. ft^{-3}.

gross heat of combustion: oven-dry weight, assume values refer to room temperature, and value is an average.

$q_V(\text{gross}) = 8017\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) \approx 4454\ \text{cal g}^{-1}$
$q_V(\text{gross}) \approx 18635\ \text{J g}^{-1}$

76CAS/CHO

SOUTHERN HARDWOOD, SAWMILL RESIDUE, PILED; solid; Material is mixed sawdust and bark residue from hardwood trees after it has been piled and exposed to the weather, collected from 6 sawmills near Baton Rouge, Louisiana. The average moisture content is 184%; average density ≈ 29.4 lb ft^{-3}.

gross heat of combustion: oven-dry weight; assume values refer to room temperature, and value is an average.

$q_V(\text{gross}) = 8046\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 4470\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 18702\ \text{J g}^{-1}$

76CAS/CHO

SPRUCE, BALSAM; *Abies lasiocarpa*; solid; ultimate analysis: carbon, 51.41%; hydrogen, 6.41%; nitrogen, 1.44%; sulfur, 0.19%; ash, 3.07%; moisture, 3.76%; proximate analysis as received: moisture, 74.35%; volatile matter, 20.20%; fixed carbon, 4.13%; ash, 0.82%.

gross heat of combustion: assume values refer to room temperature.

air-dried at 80°C (176°F)	as received
$q_V(\text{gross}) = 9547\ \text{Btu lb}^{-1}$	$q_V(\text{gross}) = 2448\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 5304\ \text{cal g}^{-1}$	$q_V(\text{gross}) \approx 1360\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 22191\ \text{J g}^{-1}$	$q_V(\text{gross}) = 5692\ \text{J g}^{-1}$

68KAI/FRI

SPRUCE, BLACK; BARK; *Picea mariana*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 2.0%; moisture content = 6.5%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

$q_V(\text{gross}) = 8246\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 4581\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 19167\ \text{J g}^{-1}$

55CHA/MIT

SPRUCE, ENGELMANN; BARK; *Picea engelmannii*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 2.5%; moisture content = 5.5%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

$q_V(\text{gross}) = 8359\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 4644\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 19430\ \text{J g}^{-1}$

55CHA/MIT

SPRUCE, NORWAY; *Pinus abies*; solid; carbon, 50.31%; hydrogen, 6.20%; nitrogen, 0.04%; ash, 0.37%.

gross heat of combustion: at 20°C (68°F); air-dried at 110°-115°C (230°-240°F); ash free.

$q_V(\text{gross}) = 9167\ \text{Btu lb}^{-1}$
$q_V(\text{gross}) = 5093\ \text{cal g}^{-1}$
$q_V(\text{gross}) = 21309\ \text{J g}^{-1}$

1883GOT

SPRUCE PINE; *Pinus glabra*; solid; samples were dried for 8 hours in a vacuum oven at 103°C (217°F).

specific heat: 333-413 K (140°-284°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.2472 + 5.577 \times 10^{-4}\ T$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = -0.0091 + 1.004 \times 10^{-3}\ T$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = -0.0389 + 4.201 \times 10^{-3}\ T$

68KAI/FRI

SPRUCE PINE, BARK; *Pinus glabra*; solid; bark specimens oven-dried at 152°C (306°F).

specific heat: 333-413 K (140°-284°F)

$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.3383 - 2.4489 \times 10^{-4}\ T + 1.5855 \times 10^{-6}\ T^2$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.7859 - 3.0645 \times 10^{-3}\ T + 5.137 \times 10^{-6}\ T^2$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 3.2882 - 1.2822 \times 10^{-2}\ T + 2.1493 \times 10^{-5}\ T^2$

68KAI/FRI

SPRUCE, RED; *Picea rubens*; solid; air-dried at 105°-110°C (221°-230°F); density, 0.39 g cm^{-3}.

specific heat: 273-379 K (32°-223°F)

C_p(Btu lb^{-1} $°F^{-1}$) = 0.332
C_p(cal g^{-1} K^{-1}) = 0.332
C_p(J g^{-1} K^{-1}) = 1.389

12DUN

SWEETGUM; *Liquidambar styraciflua*; solid; mean age = 10 years, mean basal stem diameter = 7.0 cm, mean stem bark (proportion of dry weight) = 16.0%, ash content (proportion of oven dry weight) of components of sample: wood = 0.57%, branches = 2.0%, twigs = 3.3%, bark = 5.7%, and leaves = 3.9%.

gross heat of combustion: oven dry weight basis; assume values refer to room temperature.

wood:

q_v(gross) = 8498 Btu lb^{-1}
q_v(gross) = 4721 cal g^{-1}
q_v(gross) = 19753 J g^{-1}

bark:

q_v(gross) = 8224 Btu lb^{-1}
q_v(gross) = 4569 cal g^{-1}
q_v(gross) = 19117 J g^{-1}

branches:

q_v(gross) = 8431 Btu lb^{-1}
q_v(gross) = 4684 cal g^{-1}
q_v(gross) = 19598 J g^{-1}

twigs:

q_v(gross) = 8464 Btu lb^{-1}
q_v(gross) = 4702 cal g^{-1}
q_v(gross) = 19673 J g^{-1}

leaves:

q_v(gross) = 8384 Btu lb^{-1}
q_v(gross) = 4658 cal g^{-1}
q_v(gross) = 19489 J g^{-1}

79NEE/STE

SWEETGUM; ***Liquidambar styraciflua*****;** solid; Material was collected from the southern Atlantic and Gulf coastal plains in bottom-, swamp- and wet flat-land natural stand sites. Samples were dried at 70°C (158°F) to a constant weight; reported values were averaged over all positions of similar plant tissue for each tree and six trees per species were used.

gross heat of combustion: assume values refer to room temperature; values are on a dry weight basis.

bole wood

$q_v(\text{gross}) = 8194\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4552\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19046\ \text{J g}^{-1}$

bole bark

$q_v(\text{gross}) = 7555\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4197\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 17560\ \text{J g}^{-1}$

foliage

$q_v(\text{gross}) = 8500\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4722\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19757\ \text{J g}^{-1}$

branch wood

$q_v(\text{gross}) = 8239\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4577\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 19150\ \text{J g}^{-1}$

branch bark

$q_v(\text{gross}) = 7902\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4390\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 18368\ \text{J g}^{-1}$

82GOW/FRE

SWEETGUM, BARK; ***Liquidambar styraciflua*****;** solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 5.7%; moisture content = 6.2%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

$q_v(\text{gross}) = 7450\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 4139\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 17318\ \text{J g}^{-1}$

55CHA/MIT

SYCAMORE; ***Platanus occidentalis***; solid; Each tree was separated into small parts (being less than 0.64 cm (1/4 in.) in diameter and roughly equivalent to tops and branches) and large parts with the weighted proportion of small (25%) and large (75%) material in the whole tree. Overall mean specific gravity for whole tree = 0.42 (oven dry weight and green volume). Bark proportion of whole tree = 18%.

gross heat of combustion: oven-dried, assume values refer to room temperature.

small parts

q_v(gross) = 8104 Btu lb^{-1}
q_v(gross) = 4502 cal g^{-1}
q_v(gross) = 18836 J g^{-1}

large parts

q_v(gross) = 8323 Btu lb^{-1}
q_v(gross) = 4624 cal g^{-1}
q_v(gross) = 19347 J g^{-1}

whole tree

q_v(gross) = 8269 Btu lb^{-1}
q_v(gross) = 4595 cal g^{-1}
q_v(gross) = 19221 J g^{-1}

81GEY

SYCAMORE, AMERICAN; ***Platanus occidentalis***; solid; mean age = 11.3 years, mean basal stem diameter = 9.4 cm, mean stem bark (proportion of dry weight) = 8.7%, ash content (proportion of oven dry weight) of components of sample: wood = 0.54%, branches = 1.3%, twigs = 1.6%, bark = 4.5%, and leaves = 4.8%.

gross heat of combustion: oven dry weight basis; assume values refer to room temperature.

wood:

q_v(gross) = 8561 Btu lb^{-1}
q_v(gross) = 4756 cal g^{-1}
q_v(gross) = 19899 J g^{-1}

bark:

q_v(gross) = 8602 Btu lb^{-1}
q_v(gross) = 4779 cal g^{-1}
q_v(gross) = 19995 J g^{-1}

branches:

q_v(gross) = 8741 Btu lb^{-1}
q_v(gross) = 4856 cal g^{-1}
q_v(gross) = 20318 J g^{-1}

twigs:

q_v(gross) = 8770 Btu lb^{-1}
q_v(gross) = 4872 cal g^{-1}
q_v(gross) = 20384 J g^{-1}

leaves:

q_v(gross) = 9308 Btu lb^{-1}
q_v(gross) = 5171 cal g^{-1}
q_v(gross) = 21635 J g^{-1}

79NEE/STE

SYCAMORE, AMERICAN; BARK; *Platanus heterophylla*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content ≈ 5.8%; moisture content ≈ 6.4%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

q_V(gross) = 7403 Btu lb^{-1}
q_V(gross) ≈ 4113 cal g^{-1}
q_V(gross) = 17209 J g^{-1}

55CHA/MIT

TUNDRA, INTERIOR; *Hylocomium splendens* and *Pleurozium schreberi*; solid; Sample material was top layer of black-spruce understory. Composition is ash = 34.10% and char yield = 35.5%. Char was obtained from heating the sample to 500°C (932°F) in nitrogen.

gross heat of combustion: ash-free, dry basis; assume values refer to room temperature.

fuel	char (from 500°C heating)
q_V(gross) = 8730 Btu lb^{-1}	q_V(gross) = 13780 Btu lb^{-1}
q_V(gross) = 4850 cal g^{-1}	q_V(gross) ≈ 7650 cal g^{-1}
q_V(gross) = 20290 J g^{-1}	q_V(gross) = 32020 J g^{-1}

82SUS

TUPELO, WATER; *Nyssa aquatica*; solid; Material was collected from the southern Atlantic and Gulf coastal plains in bottom-, swamp- and wet flat-land natural stand sites. Samples were dried at 70°C (158°F) to a constant weight; reported values were averaged over all positions of similar plant tissue for each tree and six trees per species were used.

gross heat of combustion: assume values refer to room temperature; values are on a dry weight basis.

bole wood	branch wood
q_V(gross) = 8361 Btu lb^{-1}	q_V(gross) = 8442 Btu lb^{-1}
q_V(gross) = 4645 cal g^{-1}	q_V(gross) = 4690 cal g^{-1}
q_V(gross) ≈ 19435 J g^{-1}	q_V(gross) = 19623 J g^{-1}

bole bark	branch bark
q_V(gross) = 8575 Btu lb^{-1}	q_V(gross) = 8532 Btu lb^{-1}
q_V(gross) = 4764 cal g^{-1}	q_V(gross) ≈ 4740 cal g^{-1}
q_V(gross) = 19933 J g^{-1}	q_V(gross) = 19832 J g^{-1}

(more)

TUPELO, WATER - Continued

foliage

q_v(gross) = 8820 Btu lb^{-1}
q_v(gross) = 4900 cal g^{-1}
q_v(gross) = 20502 J g^{-1}

82GOW/FRE

WARTY-BARKED SPINDLE TREE; *Eonymus verrucosus*; solid; Material is a tree, one of the dominant species of a 65-year-old climazonal oak forest (Quercetum petraeae-cerris) on brown forest soil, at 300 m above sea level located in the southern part of the Bukk Mountains of north Hungary. Samples were dried at 85°C (185°F), then ground and pelleted. The ash content was determined at 500°C (932°F) while the temperature was increased stepwise. Ash content of stem and branch wood = 0.7%; stem and branch bark = 6.3%; leaf = 9.5%; root = 8.1%.

gross heat of combustion: at 20 atm oxygen pressure, assume values refer to room temperature.

	dry weight basis	ash-free dry weight basis	std dev. of mean	
stem and branch wood (3 measurements)				
q_v(gross) =	8491	8548	16	Btu lb^{-1}
q_v(gross) =	4717	4749	9.0	cal g^{-1}
q_v(gross) =	19736	19870	38	J g^{-1}
stem and branch bark (5 measurements)				
q_v(gross) =	8548	9146	42.8	Btu lb^{-1}
q_v(gross) =	4749	5081	23.8	cal g^{-1}
q_v(gross) =	19870	21259	99.6	J g^{-1}
leaf (5 measurements)				
q_v(gross) =	8215	9074	82.6	Btu lb^{-1}
q_v(gross) =	4564	5041	45.9	cal g^{-1}
q_v(gross) =	19096	21092	192	J g^{-1}
root (3 measurements)				
q_v(gross) =	8305	9041	35.6	Btu lb^{-1}
q_v(gross) =	4614	5023	19.8	cal g^{-1}
q_v(gross) =	19305	21016	82.8	J g^{-1}

75PAP

WILLOW, BLACK; BARK; *Salix nigra*; solid; gross heat of combustion determined on 1 g samples of air-dried bark; ash content = 6.0%; moisture content = 6.7%.

gross heat of combustion: assume values refer to room temperature; values not corrected for moisture or ash contents; hence, are on an as-determined basis.

$q_v(\text{gross}) = 7168 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 3982 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 16661 \text{ J g}^{-1}$

55CHA/MIT

WILLOW, SANDBAR; *Salix exigua*; solid; Each tree was separated into small parts (being less than 0.64 cm (1/4 in.) in diameter and roughly equivalent to tops and branches) and large parts with the weighted proportion of small (25%) and large (75%) material in the whole tree. Overall mean specific gravity for whole tree = 0.38 (oven dry weight and green volume). Bark of whole tree = 25%.

gross heat of combustion: oven-dried, assume values refer to room temperature.

small parts

$q_v(\text{gross}) = 8017 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 4454 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 18636 \text{ J g}^{-1}$

large parts

$q_v(\text{gross}) = 7922 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 4401 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 18414 \text{ J g}^{-1}$

whole tree

$q_v(\text{gross}) = 7943 \text{ Btu lb}^{-1}$
$q_v(\text{gross}) = 4413 \text{ cal g}^{-1}$
$q_v(\text{gross}) = 18464 \text{ J g}^{-1}$

81GEY

Miscellaneous

AMATOL; solid; an explosive mixture of ammonium nitrate (AN) and trinitrotoluene (TNT). Density of cast material: 80/20 AN/TNT, 1.46 g cm^{-3}; 60/40 AN/TNT, 1.60 g cm^{-3}; 50/50 AN/TNT, 1.59 g cm^{-3}.

gross heat of combustion: 25°C (77°F); calculated from the composition of the mixture.

80/20 AN/TNT

$q_V(\text{gross}) = 2194$ Btu lb^{-1}
$q_V(\text{gross}) = 1219$ cal g^{-1}
$q_V(\text{gross}) = 5100$ J g^{-1}

60/40 AN/TNT

$q_V(\text{gross}) = 3260$ Btu lb^{-1}
$q_V(\text{gross}) = 1811$ cal g^{-1}
$q_V(\text{gross}) = 7577$ J g^{-1}

50/50 AN/TNT

$q_V(\text{gross}) = 3793$ Btu lb^{-1}
$q_V(\text{gross}) = 2107$ cal g^{-1}
$q_V(\text{gross}) = 8816$ J g^{-1}

specific heat: for the temperature range 293-353 K (64°-176°F) for 50/50 AN/TNT mixture.

$C_p = 0.383$ Btu lb^{-1} $°F^{-1}$
$C_p = 0.383$ cal g^{-1} K^{-1}
$C_p = 1.602$ J g^{-1} K^{-1}

71USA; 70COX/PIL; 68WAG/EVA

CELLULOSE NITRATE; solid; Cellulose does not form nitrate in a stoichiometric manner; the degree of nitration is measured by the percent of nitrogen in the ester.

mononitrocellulose:	$[C_6H_9NO_7]_x$; 6.76% nitrogen
dinitrocellulose:	$[C_6H_8N_2O_9]_x$; 11.11% nitrogen
trinitrocellulose:	$[C_6H_7N_3O_{11}]_x$; 14.14% nitrogen

cellulose nitrate, grade B (guncotton) $C_6H_{7.26}N_{2.74}O_{10.48}$
cellulose nitrate, grade C (type I) $C_6H_{7.36}N_{2.67}O_{10.27}$
cellulose nitrate, grade C (type II) $C_6H_{7.33}N_{2.67}O_{10.34}$
cellulose nitrate, grade D (pyroxylin) $C_6H_{7.68}N_{2.32}O_{0.64}$

gross heat of combustion: at 30°C (86°F) for $[0.115 \leq N \leq 0.135]$; N = wt. fraction nitrogen.

$q_V(\text{gross}) = 7516.8 - 25427N$ Btu lb^{-1}
$q_V(\text{gross}) = 4176.0 - 14126N$ cal g^{-1}
$q_V(\text{gross}) = 17472.4 - 59103N$ J g^{-1}

50JES/PRO; 74DEC/WAR

CORAL BRANCH TIPS; ***Eunicella papillosa***; solid; Material was the mesoskeleton of the gorgonian tropical reef-building coral (Octocorallia) from the Atlantic side of Cape Peninsula, Africa. The 2 cm apex of the branches were oven-dried at 55°C (131°F) to constant weight. Because of high $CaCO_3$ content of the tissue, correction for endothermy was used to ensure accuracy. The relationship of organic protein nitrogen to tissue weight is 3.68 ± 0.62 mg g^{-1}. There was a 50% water loss per gram dry weight. Samples were taken from 14 colonies.

gross heat of combustion: mean values were for dry weight basis; 14 samples were used; assume values refer to room temperature.

q_V(gross) = 1777 ± 379 Btu lb^{-1}
q_V(gross) = 987 ± 210 cal g^{-1}
q_V(gross) = 4130 ± 880 J g^{-1}

79VEL/KIN

CORAL BRANCHES; ***Eunicella papillosa***; solid; Material was the mesoskeleton of the gorgonian tropical reef-building coral (Octocorallia) from the Atlantic side of Cape Peninsula, Africa. The branches (excluding tips), middle sections of branches, and ramification points were oven-dried at 55°C (131°F) to constant weight. Because of high $CaCO_3$ content, the tissue correction for endothermy was used to ensure accuracy. The relationship of organic protein nitrogen to tissue weight is 3.63 ± 0.80 mg g^{-1}. There was a 41% water loss per gram dry weight. Samples were taken from 14 colonies.

gross heat of combustion: mean values were for dry weight basis; 14 samples were used; assume values refer to room temperature.

q_V(gross) = 1549 ± 327 Btu lb^{-1}
q_V(gross) = 860 ± 182 cal g^{-1}
q_V(gross) = 3600 ± 760 J g^{-1}

79VEL/KIN

DBX; solid; ammonium nitrate (AN), 21%; cyclotrimethylenetrinitramine (RDX), 21%; trinitrotoluene (TNT), 40%; aluminum, 18%; density, 1.68 g cm^{-3}.

gross heat of combustion: assume values refer to room temperature; calculated from the composition of the mixture.

q_V(gross) = 6082 Btu lb^{-1}
q_V(gross) = 3379 cal g^{-1}
q_V(gross) = 14138 J g^{-1}

specific heat: 268 K (23°F)

C_p(Btu lb^{-1} $°F^{-1}$) = 0.25
C_p(cal g^{-1} K^{-1}) = 0.25
C_p(J g^{-1} K^{-1}) = 1.05

71USA; 70COX/PIL; 68WAG/EVA; 76WAG/EVA; 73KRI/LIC

DOWTHERM A; liquid; (trademark, Dow Chemical Co.); a mixture of diphenyl and diphenyl oxide.

specific heat: 323-513 K (122°-464°F)

$$C_p(\text{Btu lb}^{-1}\ {}^\circ\text{F}^{-1}) = 0.356 + 4.111 \times 10^{-4}\ T$$
$$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) \boxminus 0.167 + 7.40 \times 10^{-4}\ T$$
$$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.699 + 3.096 \times 10^{-3}\ T$$

60BOW/GAR

FAT, WOOL; solid; (lanolin); Main constituents are cholesterol esters of higher molecular weight fatty acids.

gross heat of combustion: assume values refer to room temperature and are corrected for moisture and ash content.

$q_V(\text{gross}) \boxminus 17530 \pm 6.3$ Btu lb^{-1}
$q_V(\text{gross}) \boxminus 9741 \pm 3.5$ cal g^{-1}
$q_V(\text{gross}) = 40756 \pm 14.6$ J g^{-1}

64PAL/REI

GRAPHITE, ARTIFICIAL; solid; National Carbon Co. spectroscopic grade.

gross heat of combustion: at 25°C (77°F), average of 2 samples

$q_V(\text{gross}) = 12664 \pm 4.3$ Btu lb^{-1}
$q_V(\text{gross}) = 7035.8 \pm 2.4$ cal g^{-1}
$q_V(\text{gross}) \boxminus 32785 \pm 10$ J g^{-1}

38DEW/HAR

GRAPHITE, BUCKINGHAM; solid; 0.25% ash.

gross heat of combustion: at 25°C (77°F), average of 2 samples; corrected for ash content.

$q_V(\text{gross}) \boxminus 14106 \pm 3.6$ Btu lb^{-1}
$q_V(\text{gross}) = 7836.8 \pm 2.0$ cal g^{-1}
$q_V(\text{gross}) = 32789 \pm 8$ J g^{-1}

38DEW/HAR

GRAPHITE, CEYLON; solid; 2.2% ash.

gross heat of combustion: at 25°C (77°F), average of 2 samples; corrected for ash content.

$q_V(\text{gross}) = 14085 \pm 0.9$ Btu lb^{-1}
$q_V(\text{gross}) = 7825.0 \pm 0.5$ cal g^{-1}
$q_V(\text{gross}) = 32740 \pm 2$ J g^{-1}

38DEW/HAR

GRAPHITE, PYROLYTIC; Total gas content is less than 1 ppm; (sample 1) annealed at 2200°C (3992°F), having a density of 2.204 g ml^{-1}; (sample 2) annealed at 3000°C (5432°F), having a density of 2.265 g ml^{-1}.

gross heat of combustion: at 25°C (77°F)

sample 1	sample 2
q_V(gross) = 14121 ± 3.1 Btu lb^{-1}	q_V(gross) = 14083 ± 5.4 Btu lb^{-1}
q_V(gross) = 7844.9 ± 1.7 cal g^{-1}	q_V(gross) = 7823.9 ± 3.0 cal g^{-1}
q_V(gross) ▫ 32823.1 ± 7.1 J g^{-1}	q_V(gross) = 32735.2 ± 12.6 J g^{-1}

65LEW/FRI

GRAPHITE, TICONDEROGA; solid; 0.33% ash.

gross heat of combustion: at 25°C (77°F), average of 2 samples; corrected for ash content.

q_V(gross) = 14105 ± 1.8 Btu lb^{-1}
q_V(gross) = 7836.0 ± 1.0 cal g^{-1}
q_V(gross) ▫ 32786 ± 4 J g^{-1}

38DEW/HAR

LEATHER; solid; an animal skin or hide that has been permanently combined with a tanning agent; the tanning agent produces a transformation in the protein composition of the skin rendering it resistant to putrefactive bacteria, increasing its strength and abrasion resistance.

specific heat: 298 K (77°F)

moisture content, %	C_p(Btu lb^{-1} $°F^{-1}$)	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
vegetable-tanned			
0	0.3334	0.3334	1.3949
1.15	0.3202	0.3202	1.3397
1.32	0.3274	0.3274	1.3698
2.59	0.3280	0.3280	1.3724
3.85	0.3844	0.3844	1.6083
6.20	0.3730	0.3730	1.5606
7.83	0.3835	0.3835	1.6046
9.31	0.3844	0.3844	1.6083
10.81	0.4129	0.4129	1.7276

(more)

LEATHER - Continued

moisture content, %	C_p(Btu lb^{-1} °F^{-1})	C_p(cal g^{-1} K^{-1})	C_p(J g^{-1} K^{-1})
chrome-tanned			
0	0.3045	0.3045	1.2740
1.98	0.2918	0.2918	1.2209
3.69	0.3631	0.3631	1.5192
7.59	0.3576	0.3576	1.4962
9.39	0.3737	0.3737	1.5636
11.07	0.3893	0.3893	1.6288
13.46	0.3841	0.3841	1.6071
14.96	0.4098	0.4098	1.7146
chrome-retanned			
0	0.3404	0.3404	1.4242
1.52	0.3287	0.3287	1.3753
2.12	0.3266	0.3266	1.3665
4.23	0.3448	0.3448	1.4426
7.23	0.3458	0.3458	1.4468
9.23	0.3474	0.3474	1.4535
11.29	0.3606	0.3606	1.5088

55KAN

LEATHER, SHOE; solid; ultimate analysis in percent by weight: carbon, 42.01%; hydrogen, 5.32%; oxygen, 22.83%; nitrogen, 5.98%; sulfur, 1.00%; ash, 22.86%; proximate analysis as received in percent by weight: moisture, 7.46%; volatile matter, 57.12%; fixed carbon, 14.26%; ash, 21.16%.

gross heat of combustion: assume values refer to room temperature.

as received	dry basis
q_v(gross) = 7249 Btu lb^{-1}	q_v(gross) = 7832 Btu lb^{-1}
q_v(gross) = 4027 cal g^{-1}	q_v(gross) = 4351 cal g^{-1}
q_v(gross) = 16847 J g^{-1}	q_v(gross) = 18203 J g^{-1}

66KAI

NEAT'S FOOT OIL, REFINED; liquid; The saponification number, which is the mean molecular weight of the fatty acids present in the molecule = 194. The amount of iodine absorbed and expressed as a percentage of the molecular weight (a measure of the proportion of unsaturated fatty acid present) called the iodine number = 69.

enthalpy difference: temperature range measured -50° to 55°C (-58° to 131°F).

temperature (°C)	(°F)	H°(t)-H°(-50°C) Btu lb^{-1}	cal g^{-1}	J g^{-1}
-50	-58	0.00	0.00	0.00
-25	-13	17.89	9.89	41.38
0	32	53.37	29.65	124.06
25	77	90.58	50.32	210.54
50	122	112.18	62.32	260.75
55	131	116.57	64.76	270.96

heat of fusion: result is a mean value for temperature range -50° to 55°C (-58° to 131°F).

L_f = 34.2 Btu lb^{-1}
L_f = 19.0 cal g^{-1}
L_f = 79.5 J g^{-1}

55RIE

PB-RDX; solid; cyclotrimethylenetrinitramine (RDX), 90%; unmodified polystyrene, 8.5%; dioctyl phthalate, 1.5%.

gross heat of combustion: assume values refer to room temperature.

q_v(gross) = 5449 Btu lb^{-1}
q_v(gross) = 3027 cal g^{-1}
q_v(gross) = 12665 J g^{-1}

71USA

PENTOLITE; solid; an explosive mixture of trinitrotoluene (TNT) and pentaerythritol tetranitrate (PETN); 50/50 PETN/TNT; density, 1.65 g cm^{-3}.

gross heat of combustion: 25°C (77°F); calculated from the composition of the mixture.

q_v(gross) = 4993 Btu lb^{-1}
q_v(gross) = 2774 cal g^{-1}
q_v(gross) = 11606 J g^{-1}

71USA; 70COX/PIL

POLYVINYL NITRATE; solid; repeating unit: $C_2H_3NO_3$; used in explosive applications.

gross heat of combustion: assume values refer to room temperature.

$q_v(\text{gross}) = 5328\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 2960\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 12385\ \text{J g}^{-1}$

71USA

PROPELLANT, BAKELITE RESIN BINDER FUEL; solid; Material is a phenol-formaldehyde casting resin used as a binder fuel.

gross heat of combustion: assume values refer to room temperature.

$q_v(\text{gross}) = 12506\ \text{Btu lb}^{-1}$
$q_v(\text{gross}) = 6948\ \text{cal g}^{-1}$
$q_v(\text{gross}) = 29070\ \text{J g}^{-1}$

76GIR/ARO

PROPELLANT, OS/AP; solid; Oxygen-styrene copolymer was prepared by passing oxygen at 1 atm through styrene for 24 hours in the presence of azobisisobutyronitrile; the reaction was completed by adding benzoyl peroxide and maintaining the solution at 50°C (122°F) for another 24 hours until it became sufficiently viscous; (OS/AP) = (oxygen-styrene copolymer) - ammonium perchlorate composite propellant.

gross heat of combustion: assume values refer to room temperature.

		$q_v(\text{gross})$	
copolymer (wt. %)	Btu lb^{-1}	cal g^{-1}	J g^{-1}
30	1996 ± 18	1109 ± 10	4640 ± 42
25	2102 ± 41	1168 ± 23	4887 ± 96
20	2342 ± 14	1301 ± 8	5443 ± 33

74RAS/KIS

SANTOWAX R; liquid; (trade mark, Monsanto Co.); mixture of terphenyl hydrocarbons.

specific heat: 453-593 K (356°-608°F)

$C_p(\text{Btu lb}^{-1}\ {}^{\circ}\text{F}^{-1}) = 0.372 + 3.256 \times 10^{-4}\ T$
$C_p(\text{cal g}^{-1}\ \text{K}^{-1}) = 0.222 + 5.86 \times 10^{-4}\ T$
$C_p(\text{J g}^{-1}\ \text{K}^{-1}) = 0.929 + 2.452 \times 10^{-3}\ T$

60BOW/GAR

VACUUM CLEANER CATCH; solid; ultimate analysis on dry basis in percent by weight: carbon, 35.69%; hydrogen, 4.73%; oxygen, 20.08%; nitrogen, 6.26%; sulfur, 1.15%; ash, 32.09%; proximate analysis as received in percent by weight: moisture, 5.47%; volatile matter, 55.68%; fixed carbon, 8.51%; ash, 30.34%.

gross heat of combustion: assume values refer to room temperature.

as received	dry basis
q_V(gross) = 6390 Btu lb^{-1}	q_V(gross) = 6761 Btu lb^{-1}
q_V(gross) = 3550 cal g^{-1}	q_V(gross) = 3756 cal g^{-1}
q_V(gross) = 14854 J g^{-1}	q_V(gross) = 15714 J g^{-1}

66KAI

VASELINE; solid; semi-solid mixture of hydrocarbons having a melting point range from 38°-60°C (100°-140°F); colorless or pale yellow petroleum jelly.

gross heat of combustion: assume values refer to room temperature.

q_V(gross) = 19890 Btu lb^{-1}
q_V(gross) = 11050 cal g^{-1}
q_V(gross) = 46233 J g^{-1}

56ROT/BEC

WAX, PARAFFIN; solid; hard wax, freezing point 53°-55°C (127°-131°F); density, 0.902 g cm^{-3}; repeating unit: CH_2.

gross heat of combustion: 25°C (77°F)

q_V(gross) = 19888 Btu lb^{-1}
q_V(gross) = 11049 cal g^{-1}
q_V(gross) = 46229 J g^{-1}

56MAG

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Appendix A

A FORMULA FOR THE EMPIRICAL ESTIMATION OF THE HEATS OF COMBUSTION OF CARBONACEOUS MATERIALS

(Thomas B. Reed, Solar Energy Research Institute)

In modeling biomass reactions and reactors it is necessary to have values for the heats of formation and combustion of the various materials considered. A collection of representative data for biomass and wastes appears in the main body of this publication. In some cases, the composition of carbonaceous materials is known or can be estimated, while the heats have not been measured.

In 1978, the Institute of Gas Technology developed a formula for predicting the higher heating values (heat of combustion) (HHV, dry basis) of coal (IGT, 1978)

$$HHV = \Delta H_C = 146.58\ C + 568.78\ H - 51.53\ (O + N) - 6.58\ A + 29.45\ S\ \mathrm{Btu/lb}$$

(where C, H, O, N, S, and A are the weight percents of carbon, hydrogen, oxygen, nitrogen, sulfur, and ash respectively). This equation was derived by correlating the thermal data with the composition on more than 700 samples of coal. In the *Survey of Biomass Gasification* (Reed, 1979) Graboski and Bain used this formula, as well as two others, on 15 samples of biomass and 5 samples of char and found average errors from the measured values of 1.7% and 2.1% respectively. The error of actual measurements of composition and heats of combustion probably exceeds this, so that this suggests that the method can be used for all biomass solids.

Reed (1985) has extended the IGT equation to a wide variety of carbonaceous materials. The equation in the modified SI form is:

$$HHV \cong 0.341\ C + 1.322\ H - 0.12\ (O + N) - 0.0153\ A + 0.0686\ S\ \mathrm{kJ/g}$$

Note that in general the last two terms will be very small compared to the first three. The equation is also useful in the molecular form:

$\Delta H_C \cong 4.092\ n_C + 1.322\ n_H - 1.916\ n_{(N + O)}$ kJ/mole on a dry, ash-free, sulfur-free basis.

(where n_i is the number of moles of each element in the formula) to estimate the heat of combustion for biomass in which the formulas are given. The heat of formation can be calculated from the heat of combustion from using the equation:

$$\Delta H_f = \Delta H_C - n_C[\Delta H_c(C)] - n_H\ [\Delta H_c(H_2)/2]$$

where $\Delta H_c(C)$ and $\Delta H_c(H_2)$ are the heats of combustion of carbon and hydrogen.

The above equations were used to calculate thermal data for the biomass-related materials shown in Table A-1. This table includes representative samples of biomass, charcoals, pyrolysis oils, and tars taken from the literature but not included in this handbook. The average absolute error for each of these materials was 1.6%, 1.6%, 2.5%, and 2.5% respectively. Thus, it seems that the above equations form a reliable basis for predicting biomass thermochemical data where measured heats are not available, and can form a supplement to the representative heats of combustion shown in this publication.

Table A-1. Calculated and Measured Heats of Combustion for Various Biomass Materials Using an Empirical Formula

			Composition Dry, ash-free basis, Wt%			Heat of Combustion		Error
Name		Reference	C	H	O	Measured HHV-kJ/g	Calculated HHV-kJ/g	(Meas-Calc) Measured
Biomass Components								
Cellulose (Avicel)		Mok	43.3	6.3	50.4	NA	17.14	NA
Lignin (Indulin)		Mok	66.8	5.5	27.7	NA	26.77	NA
Biomass								
Pine Sawdust		Diebold	51.3	6.0	42.7	20.21	20.40	-0.009
Maple		Tillman	51.5	6.1	42.4	20.28	20.59	-0.015
Douglas Fir		Tillman	52.8	6.4	40.9	21.22	21.56	-0.016
Paper		Reed (1981)	46.4	6.2	47.4	18.82	18.41	0.022
Maritime Pine		Bourgeois	52.6	6.2	41.2	20.59	21.23	-0.031
Chestnut & Oak		Bourgeois	50.1	5.6	44.3	19.20	19.27	-0.004
"Typical biomass"		Reed (1985)	52.2	6.1	41.7	NA	20.89	NA
						Avg Abs error		0.016
Primary Oils								
Primary Oils R 35CS		Diebold	54.5	5.7	39.8	20.31	21.44	-0.055
Primary Oils R 40CS		Diebold	57.6	5.9	36.5	22.88	23.11	-0.010
Primary Oils R 40PS		Diebold	57.1	5.6	37.2	22.27	22.53	-0.011
						Avg Abs error		0.025
Chars	*							
Torrefied Pine	280	Bourgeois	60.8	5.7	33.5	23.90	24.30	-0.017
Torr. Chestnut & Oak	275	Bourgeois	57.8	5.3	36.9	22.70	22.36	0.015
Charcoal		Tillman	84.8	3.3	11.9	32.81	31.85	0.029
Fir Bark Char		Reed (1981)	63.6	5.1	31.3	24.49	24.75	-0.011
Grass Straw Char		Reed (1981)	68.5	5.0	26.5	25.93	26.82	-0.035
Rice Hull Char		Reed (1981)	71.6	5.2	23.3	28.18	28.50	-0.011
Redwood Charcoal	549	Reed (1981)	77.7	3.4	18.9	29.62	28.75	0.029
Oak Charcoal	571	Reed (1981)	78.6	2.6	18.9	28.02	27.96	0.002
Oak Charcoal	641	Reed (1981)	80.1	2.8	17.0	29.32	29.07	0.008
Redwood Charcoal	941	Reed (1981)	82.5	3.7	13.8	31.88	31.37	0.016
FP Char, Run 53	625	Diebold	87.7	3.8	8.4	34.40	33.98	0.012
FP Char, Run 54	625	Diebold	83.2	3.7	13.1	34.09	31.72	0.070
FP Char, Run 59	625	Diebold	84.1	3.8	12.1	33.63	32.25	0.041
FP Char, Run X	800	Diebold	92.6	1.9	5.5	33.42	33.47	-0.002
						Avg Abs error		0.016
Secondary Tars								
Sec Tars - Run 55	650	Diebold	82.2	5.3	12.5	32.44	33.59	-0.035
Sec Tars - Run 56	730	Diebold	85.4	5.0	9.6	34.08	34.60	-0.015
Sec Tars - Run 59	825	Diebold	79.3	5.9	14.8	33.92	33.09	0.024
						Avg Abs error		0.025

*Temperature of formation, degrees Celsius.

References for Appendix A

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Appendix B

ADDITIONAL INFORMATION ON HEATS OF COMBUSTION OF BIOMASS MATERIALS

The main body of this publication contains several hundred listings of measured heats of combustion of biomass materials. Still, this is only a small sampling of the extant data. Listed below are several references to additional, often special, materials for which heats have been determined. Again, this is only a sampling and shows the diversity of sources of such published information. Also listed are names and addresses of several likely continuing sources of new information on heats of combustion of biomass materials.

A. References to Correlations and General Remarks about Biomass Fuel Values

1. Jenkins, B.M. and J.M. Ebeling (1985). "Correlation of Physical and Chemical Properties of Terrestrial Biomass with Conversion" in *Energy from Biomass and Wastes IX*. Jan. 1985. Lake Buena Vista, Florida. Institute of Gas Technology.

   Develops correlations, based on experimental data for 62 samples of field crop residues, orchard prunings, vineyard prunings, food and fiber processing wastes, forest residues, and land-based crops. Correlation equations are derived to predict heating values (dry basis) from (a) ash content only; (b) ash and volatile matter from proximate analysis; (c) carbon only, from ultimate analysis; and (d) a combination of carbon, hydrogen, and oxygen content from ultimate analysis. (Several entries in this handbook come from this source.)

2. Graboski, M. and R. Bain (1981). In Reed, T.B., ed. *Biomass Gasification: Principles and Technology*, pp. 41-71. Noyes Data Corporation: Park Ridge, N.J.

   Three correlations are compared for whole biomass and for chars: (a) The historical Dulong-Berthelot equation:

   $$\text{HHV (Btu/lb)} = 146.76\ C + 621\ H - \frac{N+O-1}{8} + 39.96\ S;$$

   (b) the Tillman correlation (see below); and (c) the IGT correlations (see below).

3. Tillman, D.A. (1978). *Wood as an Energy Resource*. New York: Academic Press.

   Uses the simple correlation: $\text{HHV (Btu/lb)} = 188\ C - 718$

4. Institute of Gas Technology. (1978). *Coal Conversion Systems Technical Data Book*. DOE Contract EX-76-C-01-2286. Available NTIS, Springfield, VA.

   $$\text{HHV(Btu/lb)} = 146.58\ C + 568.78\ H - 51.53\ (O + N) - 6.58\ A + 29.45\ S$$

   This correlation, which works well for both whole biomass and chars, is discussed and applied in Appendix A of this publication.

5. Ince, Peter J. (1979). *How to Estimate Recoverable Heat Energy in Wood or Bark Fuels.* USDA, Forest Service, Forest Products Laboratory, GTR FPL 29.

   A reference source is provided for estimating the amount of heat energy that may be recovered using wood or bark fuel in a typical furnace, boiler, or hot air combustion heat recovery system. A survey of reported data on higher heating values for various species of wood and bark fuels is provided. A set of formulas of a type commonly used by combustion technologists is also provided for estimating combustion system heat losses and net recoverable heat energy per pound of fuel as-fired, based on fuel higher heating value, moisture content, and excess air, stack gas temperature, and ambient temperature assumptions.

6. Baker, A. (February 1983). "New Findings on Wood Fuel Values." *American Forest*, pp. 45-47, 51-52.

   A general discussion of the heating value and burning characteristics of cord wood for home heating.

B. References to Extensive Collections of Heats of Combustion of Biomass Materials

1. Kryla, J.M. (February 1984). *Determination of Available Heat of Combustion Data for Canadian Woody Species.* ENFOR Project P-256. Forintek Canada Corp., Ottawa, Ontario, Canada.

   A literature review was conducted to obtain reliable, experimentally determined calorific data for the various components of Canadian tree species. Information was obtained for 48 tree species native to Canada and is presented in tabular form. For indigenous species, the overall mean calorific value was found to be 21.18 MJ/kg for softwood materials (i.e. stem wood, stem bark, foliage, etc.) compared to 19.35 MJ/kg for hardwoods. Variation between reported values for a component of a particular species was found to be generally less than 5% but, in some instances, exceeded 10%. Calorific data are also presented for hybrid poplar and for several foreign species commonly planted in Canada.

2. Kuester, J.L. (1985). Arizona State University, Tempe, Arizona.

   In a multi-year program for DOE, Kuester's laboratory has measured the heats of combustion and composition of more than 100 highly diverse forms of biomass (from almond shells to skunkbrush). Heating values (dry basis) vary from 7400 to 12,700 Btu lb^{-1} for materials with ash ranging from 0.1% to 35.9%; protein from 0.1% to 25.3%; lignin from 7.8% to 28.8%; cellulose from 17.7% to 46.7%, and lipids from 5.1% to 14.9%. Results have been reported in *Conversion of Cellulosic Wastes to Liquid Fuels.* DOE Interim Report No. COD-2982-83. Contract No. DE-AC02-76CS40202, August 1982, and in a forthcoming Summary Report.

3. Fisher, J.A. (October 1984). Fiber Fuels Institute. *Standards Specifications Development. Phase I Activities, Final Report.* (Fiber Fuels Institute, 310 Cedar St., St. Paul, MN 55101)

This report contains as received and dry-basis heating values for about 50 samples of pelletized fuels from forest and agricultural residues, peat, and wastes. For many samples, ultimate and proximate analysis, ash analysis, and physical properties are also reported.

C. Selected Publications of Biomass Heats of Combustion

1. Kryla, J.M. (1985). "Calorific Value of Wood as Affected by Sample Particle Size and Radial Position in Stem." In *Fundamentals of Thermochemical Biomass Conversion.* Edited by R.P. Overend, T.A. Milne, and L.K. Mudge. Elsevier Applied Science Publishers, New York.

2. Chang, Y.PE and R.L. Mitchell. (1955). "Chemical Composition of Common North American Pulpwood Barks." *TAPPI 38* (5) 315.

3. Leong, S.K. (1983). "Determination of Calorific Values and Energy Content in Hevea Trees." *J. Rubb. Res. Inst. Malaysia 31* (1) 1.

4. Barnes, D.P. and S.A. Sinclair. (1983). "Gross Heat of Combustion of Living and Spruce Budworm-Killed Balsam Fir." *Wood and Fiber Science 16* (4) 518.

5. Goering, C.E., A.W. Schwab, M.J. Daugherty, E.H. Pryde, and A.J. Heakin. "Fuel Properties of Eleven Vegetable Oils." *Transactions of the ASAE 25* (6) 1472.

6. Hall, C.W. (1981). *Biomass as an Alternative Fuel.* Government Institutes, Inc.: Rockville, MD.

7. Howard, E.T. (1973). "Heat of Combustion of Various Southern Pine Materials." *Wood Science 5* (3) 194.

8. Corder, S.E. (August 1973). *Wood and Bark as Fuel.* Research Bulletin 14. Forest Research Laboratory, Oregon State University, Corvallis.

9. Hough, W.A. (December 1969). *Caloric Value of Some Forest Fuels of the Southern United States.* USDA Forest Service Research Note SE-120. Southern Forest Experiment Station, Asheville, NC.

10. Kossuth, S.V., D.R. Roberts, J.B. Huffman, and S-C. Wang. (1982). "Resin Acid, Turpentine, and Caloric Content of Paraquat-Treated Slash Pine." *Can. J. For. Res. 12* 489.

11. Kossuth, S.V., D.R. Roberts, J.B. Huffman, and S-C. Wang. (1984). "Energy Value of Paraquat-Treated and Resin-Soaked Loblolly Pine." *Wood and Fiber 16* (3) 398.

12. Rockwood, D.L. et al. (1983). *Energy and Chemicals from Woody Species in Florida.* ORNL/Sub/81-9050/1. University of Florida, Gainesville.

13. Bowersox, T.W., P.R. Blankenhorn, and W.K. Murphey. (1979). "Heat of Combustion, Ash Content, Nutrient Content and Chemical Content of Populus Hybrids." *Wood Science 11* (4) 257.

14. Blankenhorn, P.R., R.C. Baldwin, W. Merrill, Jr., and S.P. Ottone. (1980). "Calorimetric Analysis of Fungal Degraded Wood." *Wood Science 13* (1) 26.

15. Baileys, R.T. and P.R. Blankenhorn. (1982). "Calorific and Porosity Development in Carbonized Wood." ***Wood Science 15*** (1) 19.

D. Sources of Information-Government Programs.

1. Ranney, J.W., Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, TN 37830.

   DOE Biofuels and Municipal Waste Technology Division Woody Species Program. Major activities in short-rotation forestry for energy.

2. Forest Products Laboratory, USDA, Forest Service, P.O. Box 5130, Madison, WI 53705.

3. Forintek Canada Corporation, 800 Chemin Montreal Road, Ottawa, Ontario, Canada K16 325.

4. Northeastern Forest and Range Experiment Station, USDA, Forest Service, 705 Spear Street, P.O. Box 968, Burlington, VT 05402.

5. Intermountain Forest and Range Experiment Station, USDA, Forest Service, 507 25th St., Ogden, UT 84401.

6. North Central Forest and Range Experiment Station, USDA, Forest Service, 1992 Folwell Ave., St. Paul, MN 55108.

7. Northeastern Forest and Range Experiment Station, USDA, Forest Service, 370 Reed Rd., Broomall, PA 19008.

8. Pacific Northwest Forest and Range Experiment Station, USDA, Forest Service, 809 NE 6th Ave., Portland, OR 97232.

9. Pacific Southwest Forest and Range Experiment Station, USDA, Forest Service, 1960 Addison St. (P.O. Box 245), Berkeley, CA 94701.

10. Rocky Mountain Forest and Range Experiment Station, USDA, Forest Service, 240 W. Prospect Ave., Fort Collins, CO 80526.

11. Southeastern Forest and Range Experiment Station, USDA, Forest Service, 200 Weaver Blvd., Asheville, NC 28804.

12. Southern Forest and Range Experiment Station, USDA, Forest Service, 701 Loyola Ave., U.S. Postal Service Bldg., New Orleans, LA 70113.

13. Northern Regional Research Center (NRRC), Agricultural Research Service, USDA. 1815 N. University Street, Peoria, IL 61604.

14. Eastern Regional Research Center (ERRC), Agricultural Research Service, USDA. 600 E. Mermaid Ln., Philadelphia, PA 19118.

15. Western Regional Research Center (WRRC), Agricultural Research Service, USDA. 800 Buchanan St., Berkeley, CA 94710.

16. Southern Regional Research Center (SRRC), Agricultural Research Service, USDA. 1100 Robert E. Lee Blvd., P.O. Box 19687, New Orleans, LA 70179.

17. Beltsville Agricultural Research Center, Agricultural Research Service, USDA. Beltsville, MD 20705.

18. Russell (Richard B.) Agricultural Research Center, Agricultural Research Service, USDA. P.O. Box 5677, College Station Rd., Athens, GA 30613.

Appendix C

SYMBOLS, UNITS, CONVERSION FACTORS, ATOMIC WEIGHTS

Symbols for Thermodynamic Quantities

The symbols indicated in this Appendix are those adopted by the International Union of Pure and Applied Chemistry (IUPAC), 1969.

Symbols in parentheses are alternates, accepted but not recommended by IUPAC. Also indicated are other commonly used symbols and names of quantities not accepted by IUPAC.

Primary Symbols

T	thermodynamic temperature (absolute temperature)
K	Kelvin temperature
t,θ	Celsius temperature
R	molar gas constant
k	Boltzmann constant
q,Q	heat
w,W	work
U,(E)	internal energy
H	enthalpy: $H = U + pV$
S	entropy
A	Helmholtz energy: $A = U - TS$
J	Massieu function: $J = -A/T$
G	Gibbs energy: $G = H - TS$

NOTE: The Gibbs energy is frequently called free energy, Gibbs free energy, or Gibbs function. The commonly encountered term free energy in American work on thermodynamics almost invariably refers to Gibbs energy. This usage of the term free energy and the symbol F are being discouraged by the IUPAC because of confusion with the Helmholtz energy and the common European usage of F for the latter.

Y	Planck function: $Y \equiv -G/T$
Z	compressibility factor: $Z = pV/nRT$
C_p	heat capacity
c_p	specific heat capacity (heat capacity divided by mass)
γ,(k)	heat capacity ratio: C_p/C_v
μ	Joule-Thomson coefficient
λ,k	thermal conductivity
a	thermal diffusivity: $a = \lambda/\rho C_p$
h	coefficient of heat transfer
α	cubic expansion coefficient: $\alpha = (\partial V/\partial T)_p/V$
k	isothermal compressibility: $k = -(\partial V/\partial p)_T/V$
β	pressure coefficient: $\beta = (\partial p/\partial T)_V$

μ_B	chemical potential of substance B
λ_B	absolute activity of substance B: $\lambda_B = \exp(\mu_B/RT)$
$f,(p^*)$	fugacity
Π	osmotic pressure
I	ionic strength: $I = \frac{1}{2}\sum_i m_i z_i^2$ or $I = \frac{1}{2}\sum_i c_i z_i^2$
a_B	activity, relative activity of substance B
f_B	activity coefficient, mole fraction basis
γ_B	activity coefficient, molality basis
y_B	activity coefficient, concentration basis
ϕ	osmotic coefficient

Selected Symbols for Other Quantities in Thermodynamics

A,S	area
V	volume
t	time
m	mass
ρ	density (mass divided by volume)
p	pressure
A_r	relative atomic mass (also called "atomic weight")
M_r	relative molecular mass (also called "molecular weight")
L,N_A	Avogadro constant
N	number of molecules
$n,(\nu)$	amount of substance
x_B,y_B	mole fraction of substance B: $x_B = n_B/\sum_i n_i$
w_B	mass fraction of substance B
ϕ_B	volume fraction of substance B
m_B	molality of solute substance B (amount of B divided by the mass of solvent)
$c_B,[B]$	concentration of substance B (amount of B divided by the volume of the solution)
ρ_B	mass concentration of substance B (mass of B divided by the volume of the solution)
ν_B	stoichiometric coefficient of substance B (negative for reactants, positive for products). (The general equation for a chemical reaction is $\sum_B \nu_B B = 0$, [Example: for the reaction $H_2O \rightarrow H_2 + \frac{1}{2}O_2$, $H_2 + \frac{1}{2}O_2 - H_2O = 0$]
ξ	extent of reaction: $(d\xi = dn_B/\nu_B)$
K	equilibrium constant
α	degree of dissociation
z_B	charge number of an ion B (positive for cations, negative for anions)

Units of Measurement - International System (SI)

SI - Base Units and Supplementary Units

Quantity	Name of Unit	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
temperature	kelvin	K
electric current	ampere	A
luminous intensity	candela	cd
amount of substance	mole	mol
plane angle	radian	rad
solid angle	steradian	sr

Definitions of the SI Base Units

meter: The meter is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton-86 atom.

kilogram: The kilogram is equal to the mass of the international prototype of the kilogram.

second: The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.

kelvin: The kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. The kelvin is used both for thermodynamic temperature and for thermodynamic temperature interval.

ampere: The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible cross section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length.

candela: The candela is the luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square meter of a black body at the temperature of freezing platinum under a pressure of 101 325 newtons per square meter.

mole: The mole is the amount of substance of a system which contains as many elementary entities as there are carbon atoms in 0.012 kilogram of carbon-12.

NOTE: The elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

Prefixes

SI Symbol	Prefix Name	Multiplication Factor
T	tera	10^{12}
G	giga	10^{9}
M	mega	10^{6}
k	kilo	10^{3}
h	hecto	10^{+2}
da	deka	10^{+1}
d	deci	10^{-1}
c	centi	10^{-2}
m	milli	10^{-3}
μ	micro	10^{-6}
n	nano	10^{-9}
p	pico	10^{-12}
f	femto	10^{-15}
a	atto	10^{-18}

SI Derived Units (Partial Listing)

		Symbol for SI unit	Definition of SI unit	Other Definitions
force	newton	N	$m \cdot kg \cdot s^{-2}$	
pressure	pascal	Pa	$m^{-1} \cdot kg \cdot s^{-2}$	$N \cdot m^{-2}$
energy	joule	J	$m^{2} \cdot kg \cdot s^{-2}$	$N \cdot m$
power	watt	W	$m^{2} \cdot kg \cdot s^{-3}$	$J \cdot s^{-1}$
electric charge	coulomb	C	$A \cdot s$	
electric potential difference	volt	V	$m^{2} \cdot kg \cdot s^{-3} \cdot A^{-1}$	$W \cdot A^{-1}$
electric resistance	ohm	Ω	$m^{2} \cdot kg \cdot s^{-3} \cdot A^{-2}$	$V \cdot A^{-1}$
electric conductance	siemens	S	$m^{-2} \cdot kg^{-1} \cdot s^{3} \cdot A^{2}$	$A \cdot V^{-1}$
electric capacitance	farad	F	$m^{-2} \cdot kg^{-1} \cdot s^{4} \cdot A^{2}$	$C \cdot V^{-1}$
magnetic flux	weber	Wb	$m^{2} \cdot kg \cdot s^{-2} \cdot A^{-1}$	$V \cdot s$
inductance	henry	H	$m^{2} \cdot kg \cdot s^{-2} \cdot A^{-2}$	$Wb \cdot A^{-1}$
magnetic flux density	tesla	T	$kg \cdot s^{-2} \cdot A^{-1}$	$Wb \cdot m^{-2}$
luminous flux	lumen	lm	$cd \cdot sr$	
illumination	lux	lx	$m^{-2} \cdot cd \cdot sr$	
frequency	hertz	Hz	s^{-1}	

Other Units Exactly Defined in Terms of SI Units (Partial Listing)

Quantity	Name	Symbol	Definition
length	inch	in.	2.54×10^{-2} m
mass	pound (av.)	lb	0.453 592 37 kg
force	kilogram force	kgf	9.806 65 N
pressure	atmosphere	atm	101 325 $\mathrm{N \cdot m^{-2}}$
pressure	torr	Torr	(101 325/760) $\mathrm{N \cdot m^{-2}}$
pressure	millimeter of mercury	mmHg	$13.5951 \times 980.665 \times 10^{-2} \mathrm{N \cdot m^{-2}}$
energy	kilowatt-hour	kWh	3.6×10^{6} J
energy	thermochemical calorie*	$\mathrm{cal_{th}}$	4.184 J
energy	thermochemical Btu*	$\mathrm{Btu_{th}}$	1054.35 J**
energy	IT calorie***	$\mathrm{cal_{IT}}$	4.1868 J
energy	IT British thermal unit***	$\mathrm{Btu_{IT}}$	1055.056 J****
temperature (thermodynamic)	degree Rankine	°R	5/9 K*****
temperature	degree Celsius	°C	K******
temperature	degree Fahrenheit	°F	5/9 K*******
volume	liter	l	10^{-3} $\mathrm{m^{3}}$3

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* The thermochemical calorie and thermochemical Btu are used in this publication.

** The exact relationship is: 1 $\mathrm{Btu_{th}} = (4.1840/1.8) \times 453.59237$.

*** IT refers to International Tables (International Steam Tables).

**** The exact relationship is: 1 $\mathrm{Btu_{IT}} = (4.1868/1.8) \times 453.59237$

***** [T(°R) = 1.8T(K)]; [T(°R) = t(°F) + 459.67]; [T(°R) = 1.8t(°C) + 491.67].

****** [t(°C) = T(K) - 273.15].

******* [t(°F) = 1.8t(°C) + 32].

Conversion Factors

Subscript: th - thermochemical units
Subscript: IT - International Steam Table units
Abbreviations: calorie - cal
joule - J
British thermal unit - Btu
gram - g
pound - lb
Fahrenheit degree - °F
Celsius degree - °C
Kelvin - K

In the chemical literature, authors occasionally identify the calorie or British thermal unit as either th or IT, but rarely is the joule subscripted in any way. An absence of any subscripting to indicate the kind of energy unit is the more common occurrence.

Energy Conversion Factors

1 cal$_{th}$ = 4.1840 J
1 cal$_{IT}$ = 4.1868 J
1 Btu$_{th}$ = 1054.35 J
1 Btu$_{IT}$ = 1055.056 J

1 cal$_{th}$/g = 1.8 Btu$_{th}$/lb
1 cal$_{IT}$/g = 1.8 Btu$_{IT}$/lb
1 cal$_{th}$/g = 4.1840 J/g
1 cal$_{IT}$/g = 4.1868 J/g
1 cal$_{th}$/g = 1.798796 Btu$_{IT}$/lb
1 Btu$_{th}$/lb = 2.326000 J/g
1 Btu$_{IT}$/lb = 2.324444 J/g

1 Btu$_{th}$/(lb)(°F) = 1 cal$_{th}$/(g)(K)
1 Btu$_{IT}$/(lb)(°F) = 1 cal$_{IT}$/(g)(K)

Btu$_{th}$/(lb)(°F) = 4.1840 J/(g)(K)
Btu$_{IT}$/(lb)(°F) = 4.1868 J/(g)(K)

Temperature Conversion Factors:

1.8(°C) + 32 = °F

273.15 + °C = K

[(459.67) + °F]/1.8 = K

(1.8)K = °R

(1.8)K = 459.67 + °F

°R = 459.67 + °F

Physical Constants*

Gas Constant, R	82.0568 (26) cm^3 atm mol^{-1} K^{-1}
	8.31441 (26) J mol^{-1} K^{-1}
	1.98719 (6) cal$_{th}$ mol^{-1} K^{-1}
Molar Gas Volume, V_m	0.02241383 (70) m^3 mol^{-1}

(at To = 273.15 K and p_o = 1 atm)

$V_m = R\ To/p_o$

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*Physical Constants were taken from the International Council of Scientific Unions, CODATA Bulletin No. 11, Dec. 1973. The digits in parentheses following a numerical value represent the standard deviation of that value in terms of the final listed digits.

Atomic Weights of the Elements 1983

(Scaled to $\underline{A}_r$ (^{12}C)=12)

N.E. Holden and R.L. Martin, *Pure & Appl. Chem.* **56**, 653-674 (1984).

IUPAC Commission on Atomic Weights and Isotopic Abundances

The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The footnotes to this Table elaborate the types of variation to be expected for individual elements. The values of $\underline{A}_r$(E) given here apply to elements as they exist naturally on earth. When used with due regard to the footnotes they are considered reliable to ±1 in the last digit, unless otherwise noted.

Alphabetical order in English

Names	Symbol	Atomic Number	Atomic Weight	Footnotes
Actinium*	Ac	89		A
Aluminium	Al	13	26.98154	
Americium*	Am	95		A
Antimony (Stibium)	Sb	51	121.75 ± 3	
Argon	Ar	18	39.948	g r
Arsenic	As	33	74.9216	
Astatine*	At	85		A
Barium	Ba	56	137.33	g
Berkelium*	Bk	97		A
Beryllium	Be	4	9.01218	
Bismuth	Bi	83	208.9804	
Boron	B	5	10.811 ± 5	m r
Bromine	Br	35	79.904	
Cadmium	Cd	48	112.41	g
Caesium	Cs	55	132.9054	
Calcium	Ca	20	40.078 ± 4	g
Californium*	Cf	98		A
Carbon	C	6	12.011	r
Cerium	Ce	58	140.12	g
Chlorine	Cl	17	35.453	
Chromium	Cr	24	51.9961 ± 6	
Cobalt	Co	27	58.9332	
Copper	Cu	29	63.546 ± 3	r
Curium*	Cm	96		A
Dysprosium	Dy	66	162.50 ± 3	g
Einsteinium*	Es	99		A
Element 104* *(a)*	Unq	104		A
Element 105* *(b)*	Unp	105		A
Element 106* *(c)*	Unh	106		A
Element 107* *(d)*	Uns	107		A
Erbium	Er	68	167.26 ± 3	g
Europium	Eu	63	151.96	g
Fermium*	Fm	100		A
Fluorine	F	9	18.998403	

(a)-(d) Systematic names: *(a)* Unnilquadium; *(b)* Unnilpentium; *(c)* Unnilhexium; *(d)* Unnilseptium

Atomic Weights 1983 (cont'd)

Names	Symbol	Atomic Number	Atomic Weight	Footnotes			
Francium*	Fr	87					A
Gadolinium	Gd	64	157.25 ± 3	g			
Gallium	Ga	31	69.723 ± 4				
Germanium	Ge	32	72.59 ± 3				
Gold	An	79	196.9665				
Hafnium	Hf	72	178.49 ± 3				
Helium	He	2	4.002602 ± 2	g		r	
Holmium	Ho	67	164.9304				
Hydrogen	H	1	1.00794 ± 7	g	m	r	
Indium	In	49	114.82	g			
Iodine	I	53	126.9045				
Iridium	Ir	77	192.22 ± 3				
Iron	Fe	26	55.847 ± 3				
Krypton	Kr	36	83.80	g	m		
Lanthanum	La	57	138.9055 ± 3	g			
Lawrencium*	Lr	103					A
Lead	Pb	82	207.2	g		r	
Lithium	Li	3	6.941 ± 2	g	m	r	
Lutetium	Lu	71	174.967	g			
Magnesium	Mg	12	24.305				
Manganese	Mn	25	54.9380				
Mendelevium*	Md	101					A
Mercury	Hg	80	200.59 ± 3				
Molybdenum	Mo	42	95.94				
Neodymium	Nd	60	144.24 ± 3	g			
Neon	Ne	10	20.179	g	m		
Neptunium*	Np	93					A
Nickel	Ni	28	58.69				
Niobium	Nb	41	92.9064				
Nitrogen	N	7	14.0067	g			
Nobelium*	No	102					A
Osmium	Os	76	190.2	g			
Oxygen	O	8	15.9994 ± 3	g		r	
Palladium	Pd	46	106.42	g			
Phosphorus	P	15	30.97376				
Platinum	Pt	78	195.08 ± 3				
Plutonium*	Pu	94					A
Polonium*	Po	84					A
Potassium (Kalium)	K	19	39.0983				
Praseodymium	Pr	59	140.9077				
Promethium*	Pm	61					A
Protactinium*	Pa	91					A
Radium*	Ra	88					A
Radon*	Rn	86					A
Rhenium	Re	75	186.207				
Rhodium	Rh	45	102.9055				
Rubidium	Rb	37	85.4678 ± 3	g			
Ruthenium	Ru	44	101.07 ± 2	g			
Samarium	Sm	62	150.36 ± 3	g			

Atomic Weights 1983 (cont'd)

Names	Symbol	Atomic Number	Atomic Weight	Footnotes
Scandium	Sc	21	44.95591 ± 1	
Selenium	Se	34	78.96 ± 3	
Silicon	Si	14	28.0855 ± 3	r
Silver	Ag	47	107.8682 ± 3	g
Sodium (Natrium)	Na	11	22.98977	
Strontium	Sr	38	87.62	g
Sulfur	S	16	32.066 ± 6	r
Tantalum	Ta	73	180.9479	
Technetium*	Tc	43		A
Tellurium	Te	52	127.60 ± 3	g
Terbium	Tb	65	158.9254	
Thallium	Tl	81	204.383	
Thorium*	Th	90	232.0381	g X
Thulium	Tm	69	168.9342	
Tin	Sn	50	118.710 ± 7	
Titanium	Ti	22	47.88 ± 3	
Tungsten (Wolfram)	W	74	183.85 ± 3	
Uranium*	U	92	238.0289	g m Y
Vanadium	V	23	50.9415	
Xenon	Xe	54	131.29 ± 3	g m
Ytterbium	Yb	70	173.04 ± 3	
Yttrium	Y	39	88.9059	g
Zinc	Zn	30	65.39 ± 2	
Zirconium	Zr	40	91.224 ± 2	g

g geologically exceptional specimens are known in which the element has an isotopic composition outside the limits for normal material. The difference between the atomic weight of the element in such specimens and that given in the Table may exceed considerably the implied uncertainty.

m modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic separation. Substantial deviations in atomic weight of the element from that given in the Table can occur.

r range in isotopic composition of normal terrestrial material prevents a more precise $\underline{A}_r(E)$ being given; tabulated $\underline{A}_r(E)$ value should be applicable to any normal material.

A Radioactive element that lacks a characteristic terrestrial isotopic composition.

X Thorium has a well defined (mononuclidic) composition in minerals with only rare exceptions. In certain places, however (most notably in ocean water), measurable quantities of Thorium 230 (Ionium) can be found.

Y Uranium is the only element with no stable isotopes but which has a characteristic terrestrial composition of long-lived isotopes such that a meaningful atomic weight can be given for natural samples.

* Element has no stable isotopes.

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