Energy Thermodynamics of Ethanol Metabolism

This paper will analyze the claim that alcohol (ethanol) provides 7 calories per gram in human metabolism.

Energy Considerations

The reaction from ethanol to carbon dioxide and water is a complex one that proceeds in four steps. The Gibbs Free Energy of Formation ($\Delta G_f$) is shown below for each step with the $\Delta G_f$ values published in the CRC Handbook of Chemistry & Physics. (See http://en.wikipedia.org/wiki/Gibbs_Free_Energy)

Complete Reaction:
\[ C_2H_6O(\text{Ethanol}) \rightarrow C_2H_4O(\text{Acetaldehyde}) \rightarrow C_2H_4O_2(\text{acetic Acid}) \rightarrow \text{Acetyl-CoA} \rightarrow 3H_2O + 2CO_2. \]

**Step One:**
Ethanol: $-174.8$ kJ/mol  
Ethanal (Acetaldehyde): $-127.6$ kJ/mol  
$\Delta G_f^1 = -127.6 + 174.8 = 47.2$ kJ/mol (Endergonic)  
$\Sigma \Delta G_f = 47.2$ kJ/mol (Endergonic)

**Step Two:**
Ethanal: $-127.6$ kJ/mol  
Acetic Acid: $-389.9$ kJ/mol  
$\Delta G_f^2 = -389.9 + 127.6 = -262.3$ kJ/mol (Exergonic)  
$\Sigma \Delta G_f = -215.1$ kJ/mol (Exergonic)

**Step Three:**
Acetic Acid: $-389.9$ kJ/mol  
$3H_2O+2CO_2$: $-1500.1$ kJ/mol  
$\Delta G_f^3 = -1500 + 389.6 = -1110.5$ kJ/mol (Exergonic)  
$\Sigma \Delta G_f = -1325.3$ kJ/mol (Exergonic)

**Step Four:**
We can skip the Acetyl-CoA (Step 4), because the Gibbs energy is a State function, for which thermodynamic values are unknown. See http://en.wikipedia.org/wiki/State_function.

Discussion of the calculations:

If catabolism of alcohol goes all the way to completion, then, we have a very exothermic event yielding some $1325.3$ kJ/mol of energy. If the chemical reaction stops part way through the metabolic pathways, as happens when acetic acid is excreted in the urine, then not nearly as much energy can be derived from the alcohol. The energy yield falls between theoretical lower and upper limits from $215.1$ kJ/mol to $1325.3$ kJ/mol. It is also important to note that initiation of Step 1 of this reaction is endothermic, requiring $47.2$ kJ per mol of ethanol, or about three molecules of ATP (adenosine triphosphate) required for each molecule of ethanol.

Notes:

The words “alcohol”, “ethanol”, and “EtOH” are all synonymous for the substance with formula $C_2H_5OH$. $1.00$ mol of EtOH ($C_2H_5OH$) weighs $46$ grams. $46$ grams/mol $\times 7$ kcal/gram = $322$ kcal/mol. ($7$ kcal/gm idea)

1 kilocalorie (kcal) = $4.1868$ kiloJoule (kJ). (Known conversion factors of relevant energy units)

Since 1 kcal = $4.1868$ kJ, then 322 kcal/mol $\times 4.1868$ kJ/kcal $\approx 1348$ kJ/mol. The figure of 1348 kJ/mol in this analysis is close to the official maximum theoretical energy yield limit (1325.3 kJ/mol) as shown above.

$1325.3$ kJ/mol $\div 4.1868$ kJ/kcal $= 316.5$ kcal/mol. $316.5$ kcal/mol $\div 46$ grams/mol $= 6.88$ kcal/gram.

Thus the value $7$ kcal/gram is approximately the theoretical maximum energy yield. (Slightly larger by $1.74\%$)

By a similar analysis, the theoretical minimum energy yield is $1.12$ kcal/gram.

$1.12$ kcal/gram $\leq$ energy yield of alcohol metabolism $\leq 6.88$ kcal/gram