Chapter 10  Energy metabolism
Energy

- Most important item in diet.
- Feeding standard are base on energy need.
- defined as the ability to perform work.

- Derived from most organic compound ingested by an animal by partial on complete oxidation of molecules from ingested or stored form.

- Energy transfer from one chemical reaction to another bound found as ATP and others.

- All life process and animal activities such as walking, chewing, digestion, maintenance of body temp. maintenance of ion gradient, hepatic synthesis, glucose absorption, storage of glycogen, fat, protein, body metabolism (movement of energy from one from to another),
• Including:
  * from chemical energy to heat.
  * from chemical to mechanical energy (肌肉活動).
  * from chemical to electrical (葡萄糖氧化成神經組織之電子活力).
Energy terminology
chemical energy is typically measured in terms of heat produced.
Cal: heat required to raise 1g water from 14.5°C to 15.5°C
1Cal = 4.1855 joules,
Kilocalorie (Kcal)
Megacalorie (Mcal).
Fig 10.1 Schematic representation of the energy flow, NRC (1981)
Figure 10.1  Schematic diagram of energy utilization by animals. The reader should be aware that some publications have chosen to use different abbreviations and some added terminology. Those used in this figure have been in use many years, and, thus, the authors see no reason to change. Losses of energy by way of the feces, urine, and gaseous products cannot be utilized or recovered by the animal (unless it practices coprophagy). Heat produced in the animal body—such as those items listed under ME or NE maintenance—can be useful in maintaining a stable body temperature unless the animal is in a heat-stress situation. Recovered energy may range from almost nil (hair, wool) to more than 30% of GE for high-producing dairy cows.
• **Gross energy**: adiabatic bomb calorimeter as the increase in temperature
• Of a known amount of water upon complete oxidation of a sample.
• Carbohydrate: 4.1 Kcal/g
• Protein : 5.7 Kcal/g
• Fat : 9.4 Kcal/g
• others in Table 10.1
Digestible energy (DE):

- **DE = IE – FE**
- FE loss range 10% or less to 80% or more.
- *fecal loss include: undigestible food residue.*
- : sloughing of cell from GI tract lining.
- : undigested microbes and their metabolic byproduct
- True digestible energy (TDE)
  - = IE – FiE – HfE – GE
  - = IE – (FE – FeE – FmE) – HfE – GE
- **FE = fecal energy**
- **Fie = fecal energy of food origin**
- **FeE = fecal energy of endogenous**
- **FmE = fecal energy of metabolic source**
- **HfE = heat of fermentation**
- **GE = gas losses**
Figure 10.2 A graphic illustration of energy terminology and the different systems of expressing energy value of feeds. The bar chart shows relative energy losses when a mixed diet is fed to a lactating dairy cow. Reproduced by permission of P. W. Moe, USDA, ARS, Beltsville, MD.
Figure 10.3 A theoretical example of the proportional changes in energy balance with increasing intake by a ruminant. The proportion of energy lost in methane declines somewhat with increasing intake. Fecal losses increase because of reduction of digestibility with increased consumption. From Reid (1962).
• Total digestible nutrient (TDN)
• TDN = DCP + DNFE + DCF + 2.25(DEF)
• 1Kg TDN = 4.4 Mcal DE

*DE和TDN並未考慮分佈於消化(digestion)和代謝(metabolism)過程所損失的能量, 高估高纖維原料之可利用能量.
Metabolizable energy (ME)

- $\text{ME} = \text{IE} - \text{FE} - \text{UE} - \text{GE}$

- 考慮消化與代謝過程所損失之能量.

- **Gaseous product of digestion (GE)**
  - 消化道中因微生物發酵所產生之氣體損失之能量，以methane
  - (CH$_4$) 為主要，H$_2$，CO$_2$，acetone，ethane，H$_2$S少量.

- *GE大約為IE之8%，如intake增加則降至6-7%.
- *UE = energy from nonutilized absorbed compound (UiE),
  - end product of metabolic process (UmE),
  - end product of endogenous origin (UeE).
- *攝取excess protein, forage consumed, oil, must be detoxified
  product時，UE會增加.
• $ME = 0.82 \times DE$
• 因为需要收集gas，所以较少被测定。
• 用于家禽之能量评估
• **N-corrected metabolizable energy (MEn):**
• 經氮矯正 (Nitrogen retained or lost) 後之 ME.
• MEn = ME — (k × TN)
• k is constant, 7.45Kcal/g of nitrogen retained in body tissue. (哺乳動物) 8.22Kcal/g for birds.
• TN is total nitrogen retain or lost.
• *ME之測定較常應用於家禽
Net energy

• NE=ME – HI (heat increment)
• –HF(heat fermentation)
• -HP(heat production in the fasting animal).

• NE is available to the animal for maintenance, various production purposes.
Heat increment (HI)

- The heat production associated with nutrient digestion and metabolism.
- The metabolism in the liver is the most of HI.
- Lean meat for dog: HI amount to 30-40% of GE. Fat 15%, sucrose 6%, starch 20-22%.
- **The amount of HI**: if most of the material is absorbed and deposit in the tissue, the HI us very low. Incomplete protein result in oxidation of most amino acid and a high HI.
Heat production (HE)

- The energy lost from a animal system in a form other than as a combustible compound.

Including:
- Basal metabolism: energy required in the fasting and resting state. This energy is used to maintain essential cellular activity: respiration, blood circulation.

Basal metabolic rate (BMR) = animal in a thermoneutral environment, postabsorptive state, quiet, sexual repose, resting.
= as fasting heat production (FHP).
• Heat production =
• + heat of activity.
• + heat of digestion and absorption
• + heat of fermentation
• + heat of waste product formation and excretion
  + heat of thermal regulation
+ heat of product formation
<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>ENERGY COST PER KG WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing (compared to lying)</td>
<td>2.39 Kcal</td>
</tr>
<tr>
<td>Changing position (lying down and standing)</td>
<td>0.06 Kcal</td>
</tr>
<tr>
<td>Walking (horizontal component)</td>
<td>0.62 Kcal/km</td>
</tr>
<tr>
<td>Walking (vertical component)</td>
<td>6.69 Kcal/km</td>
</tr>
<tr>
<td>Eating (prehension and chewing)</td>
<td>0.60 Kcal/h</td>
</tr>
<tr>
<td>Ruminating</td>
<td>0.48 Kcal/h</td>
</tr>
</tbody>
</table>

• **Heat increment (HiE)** = 在適溫帶時，動物消耗食物所產生之熱.

•  \[ \text{HiE} = \text{HdE} + \text{HfE} + \text{HwE} + \text{HrE} \]
Recovered energy (RE) = defined as the energy retained as part of the body or voided as a useful product.

- \[ \text{RE} = \text{tissue energy} + \text{lactation energy (or other product energy)} \]

Net energy (NE)

- \[ \text{RE} = \text{ME} - \text{HE} \]
Methods of measure heat production (HP)

- Calorimetry
- Animal loss heat = sensible heat (convection, conduction, reduction) evaporation heat (excreta, skin, respiratory tract)
- by directly calorimetry.
- by indirectly calorimetry

- heat production = result of oxidation of organic compounds.
- = calculated from O₂ consumed and CO₂ produced
- and excreted urea (不完全燃焼), and gas (methane)
- HE = 3.886 O₂+1.200 CO₂−0.518 CH₄−1.431 N
- O₂, CO₂, CH₄ in liter; N in grams (尿氮).
- 因為CH₄, N很少→省略
• Carbon-Nitrogen balance

此法乃利用energy retained於體內，乃以protein及fat之型態，而CH₂O很少，所以測定C, N intake 及C, N的loss (from尿, 尿, CO₂, CH₄)，而body protein含16%N及51.2%C.

• N balance: (intake – loss) x 6.25 = body protein accretion.

體蛋白質量 x 0.512 = C accretion in body protein.

(intake – loss)c – body protein C = C in fat

C balance ÷ 0.746 (assuming fat contains 74.6%) = accretion fat.

Calculation of the energy content of protein and fat accretion = recovered energy C
## TABLE 9.5. Example of a Nitrogen-Carbon Balance

<table>
<thead>
<tr>
<th>Item</th>
<th>Nitrogen, g</th>
<th>Carbon, g</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intake</td>
<td>Outgo</td>
</tr>
<tr>
<td>Feed</td>
<td>390.55</td>
<td>—</td>
</tr>
<tr>
<td>Feces</td>
<td>—</td>
<td>105.69</td>
</tr>
<tr>
<td>Urine</td>
<td>—</td>
<td>263.76</td>
</tr>
<tr>
<td>Gases</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Gain to body</td>
<td>—</td>
<td>21.10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>390.55</td>
<td>390.55</td>
</tr>
</tbody>
</table>

Note: Based upon a content of $52.54^a$ percent carbon and $16.67^a$ percent nitrogen in fat-free, ash-free flesh and of 76.5 percent carbon in fat, the following calculations gave the protein and fat gained: (1) 21.1 g nitrogen gain divided by 0.1667 equaled 126.6 g **protein gain**. (2) 126.6 g protein times 0.5254 equaled 66.5 g carbon in protein. (3) 680.1 g carbon gain minus 66.5 equaled 613.6 g carbon gained as fat. (4) 613.6 divided by 0.765 equaled 802.1 g **fat gain**.  

$^a$Figures used by later workers are slightly different.

• Comparative slaughter
• Animal飼餵正常之飼糧 2週，分成兩組
一組屠宰→分析body composition, energy content.
另一組經飼養一段時間，後屠宰→分析body composition, energy.
Retained energy (RE) = body energy difference between two groups.
Metabolic weight, Metabolic size

- Scaling coefficient for weight
- 能量產生與body surface有關, body surface = W^{0.67}
- Brody and Kleiber顯示interspecies之間以W^{0.75}較適當, 且被引用.
Basal metabolism
Factor affecting basal metabolism
Maintenance
Energy expenditure and the environment

- *
- heat production by “tissue metabolism” and “fermentation in GI”
- dissipate heat by “evaporation”, “radiation” and “conduction”.
- Fig 10.6 showed
- 兩者(heat production，heat dissipate)受維持體溫恆定之調整.
- Fig 10.6 showed 環境溫度與動物之恆溫調整.
- 適溫帶下，HE之產生不受溫度影響，而受metabolism, feed intake, efficiency of energy use.
- 適溫帶下，體溫受heat dissipation之調控.
當溫度高於適溫帶時 (Tuc): *蒸發散熱↑，藉流汗，喘氣。
*攝食量↓。
*因dissipating heat增加，代謝速率↑，體溫↑。

當溫度低於適溫帶時 (Tic): *因正常之metabolism fermentation 產生之HE不足以維持體溫，增
加代謝，產生熱 (稱之cold thermogenesis)。

Tuc與Tic之溫度 (適溫帶範圍)受下列二因素而改變:
1. rate of heat production (因feed intake, body condition, physiological state的影響)。
2. animal ability to dissipate or conserve heat.
Figure 10.6  A schematic representation of the effect of environmental temperature on thermoregulation by the animal.
• Animal acclimatization
• modification in behavior: 利用生理現象 (physiological adaptation) 增加或減少熱產生.
• 如: basal metabolism
• respiration rate
• distribution of blood flow to skin lungs
• feed, water intake
• digesta passage
• hair coat
• shivering sweating
*nonstructural components*之消化率因high level of intake而降低。

\[ \Delta de = (L - 1)(0.107 - 0.113de) \]

\( \Delta de \)指每增加1倍維持量時，消化率之改變。

\( L \):指維持量時之採食量。

\( De \):指採食量為1倍維持量時之消化率。

例：如採食量為2倍維持量時，消化率之改變量。

*1*倍維持量之採食量時，消化率為70% (0.7)，而提高至兩倍維持量時，其消化率則為

\[ \Delta de = (2 - 1) \left[ 0.107 - 0.113(0.7) \right] = 0.038 \]

所以2倍維持量之採食量，其消化率為0.672

5倍維持量之採食量，其消化率為0.558

*消化率越低者，採食量越高，其消化率受影響之程度越明顯。*
Energy termination used in ration formulation and feeding standards

- GE
- DE, TDN: swine horse
- ME: poultry
- DE, TDN, ME: sheep
- NEm: $77 \text{Kcal} \times \text{BW}^{0.75}$
- NE g
end
• *以methane (CH4) 及尿損失之能量, 隨採食量增加, 消化率降低 而降低
• (intake ↑, dig ↓ →loss of CH4 and urine energy ↓).
• 所以消化率↓, GE及UE之損失量↓, 所以ME受feed intake影響之程度較DE為低.
Utilization of ME

- ME used for maintenance, tissue gain, lactation, muscular activity.

\[ \text{ME} = \text{fasting heat production (HE)} + \text{heat of activity (HJE)} + \text{heat energy required to maintain body temp} + \text{heat increment of the food consumed (HJE)} \]

- \( \text{ME} = \text{HE} \) as recovered energy (RE) = 0
MEm used two types:

1. service function
   =組織或器官維持正常功能所需，
   - 如circulation, respiration, liver and kidney work
   - (detoxification, maintenance of body osmolarity and
   - pH, gluconeogenesis) and nervous function, 約佔
   - HeE的35-50%.

2. cell maintenance function
   = ion transport, protein turnover, lipid turnover. (即
   metabolic functions)，此三部分為主要需能之function, 約佔HeE的
   - 30~50%.
   - 其他亦含glycogen synthesis, ketogenesis, urea,
   - RNA, DNA, synthesis---------
• Maintenance energy expenditure vary with

• 1. age:呈曲線性減少 with age. (越成熟, tissue 及 organ 生長 緩慢).

• 2. body size: mean 70Kcal/W 0.75, sheep 63Kcal/W 0.75, cattle 77Kcal/W 0.75.

• 3. breed: Bos indicus required 10% less than breed of Bos taurus cattle dairy purpose require 20% more than beef breed.

• 4. sex: male greater than female about 15%.

• 5. physiological state: pregnancy, lactating 多 20%.

• 6. season: summer (維持所需能量最高), winter (最低).

• 7. temp.

• 8. previous nutrition: low level 是 high level intake 的 58%.

• 9. grazing expend more energy than penned to be 10-20%.

• 10. production: 高生產量→高維持量.
• Retained energy
• energy retention as tissue energy, milk, conceptus.
• 1. NEg = energy content of body gain.
  = heat of combustion of the body protein and fat gains which is 5.6 and 9.4 Kcal/g, respectively.
• RE as a function of weight and rate of gain (EBG)
  RE = 0.0635W^{0.75} + EBG^{1.097}
• 2. NEI = energy content of the milk produced.
• 3. NEy = energy retained in the fetus and associated tissues.