The Science of Biomass Stoves

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THE SCIENCE AND ART OF COOKING

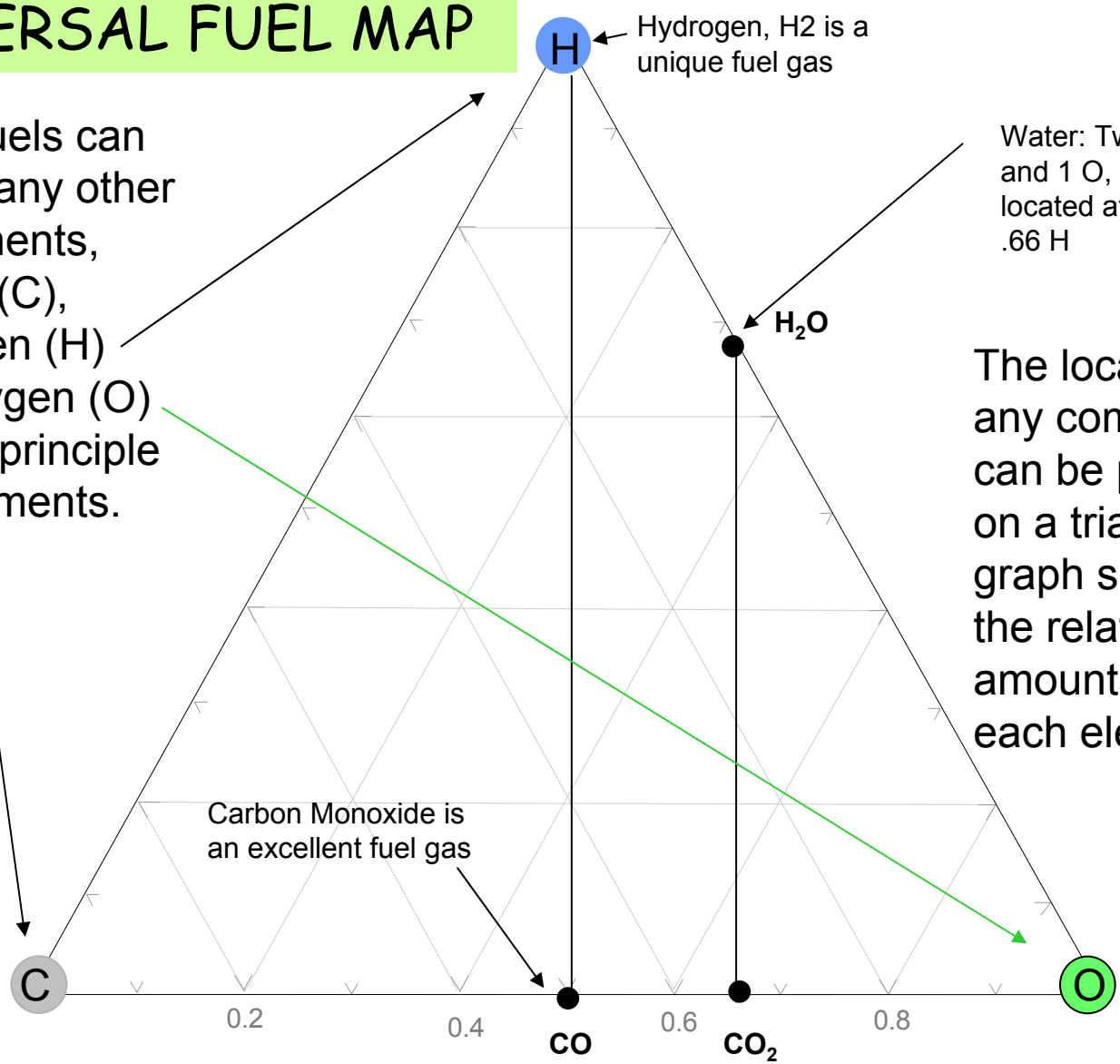
- **Cooking is more complex than nuclear science**
  - Nuclear science complete in 100 years
  - Cooking was an art for 100,000 years
  - Great progress in last 100 years – mostly in new fuels and electricity, unavailable in much of the world
- **Cooking improvements have been science based**
  - Not all cooks are science based
  - Stove designers should be science based
- **Biomass Cooking Science based on**
  - FUEL PYROLYSIS – to 400 °C
  - GASIFICATION – to 1000 °C
  - COMBUSTION – to 2000 °C
- P-G-C understanding needed for designing stoves!

FUELS

- Energy source ≠ Fuel
- Energy sources: Solar, wind, PV, geothermal …must be used as they occur
- **Fuels** provide chemical storage of energy
  - Always available
  - Easy to convert to high temperature, electric power

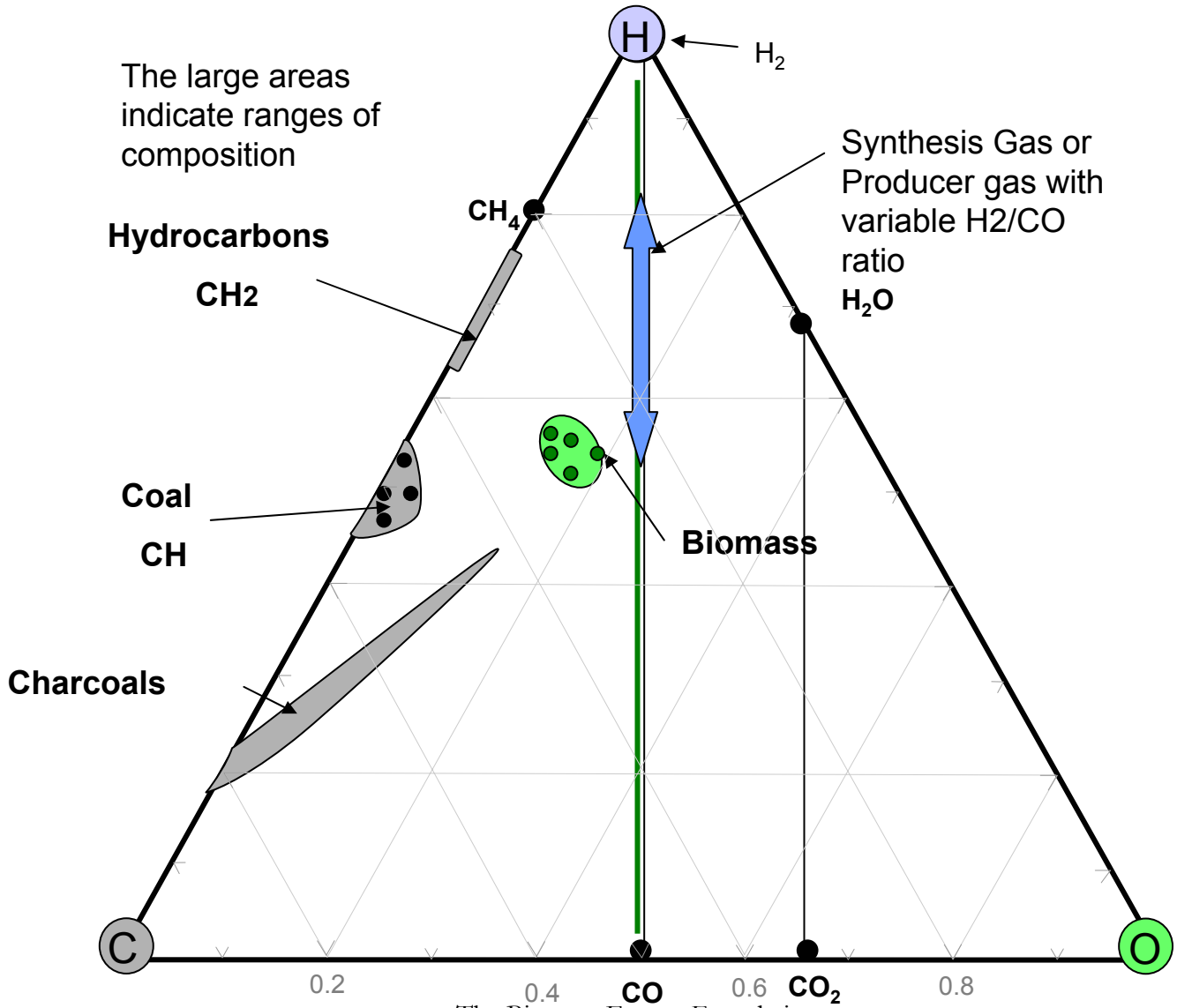
UNIVERSAL FUEL MAP

While fuels can have many other components, carbon (C), hydrogen (H) and oxygen (O) are the principle fuel elements.

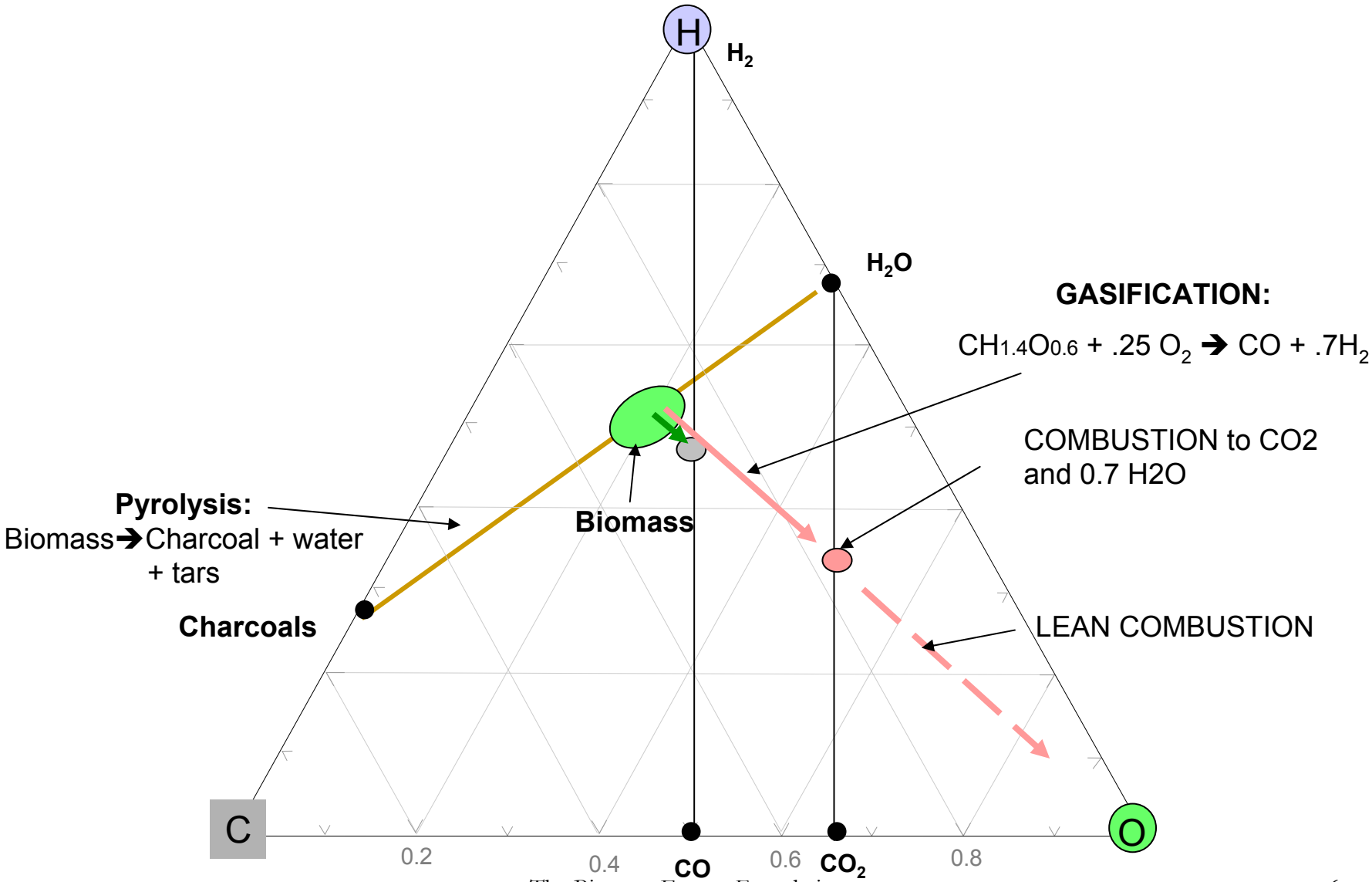


The location of any compound can be plotted on a triangular graph showing the relative amounts of each element.

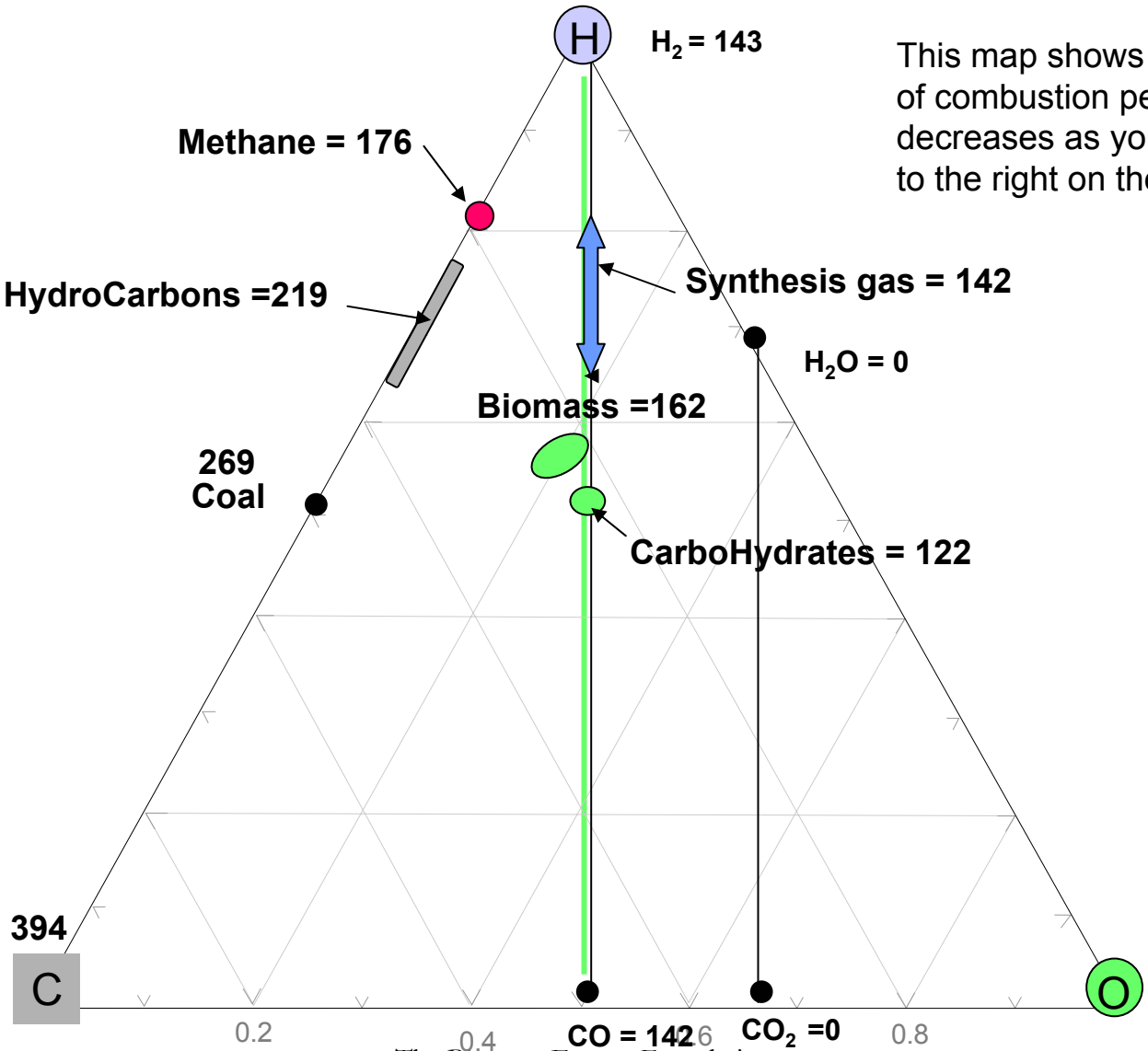
SIMPLIFIED FUEL FORMULAS



BIOMASS CONVERSION ROUTES



ATOM ENERGIES



This map shows how the heat of combustion per atom decreases as you move up and to the right on the chart.

COMBUSTION

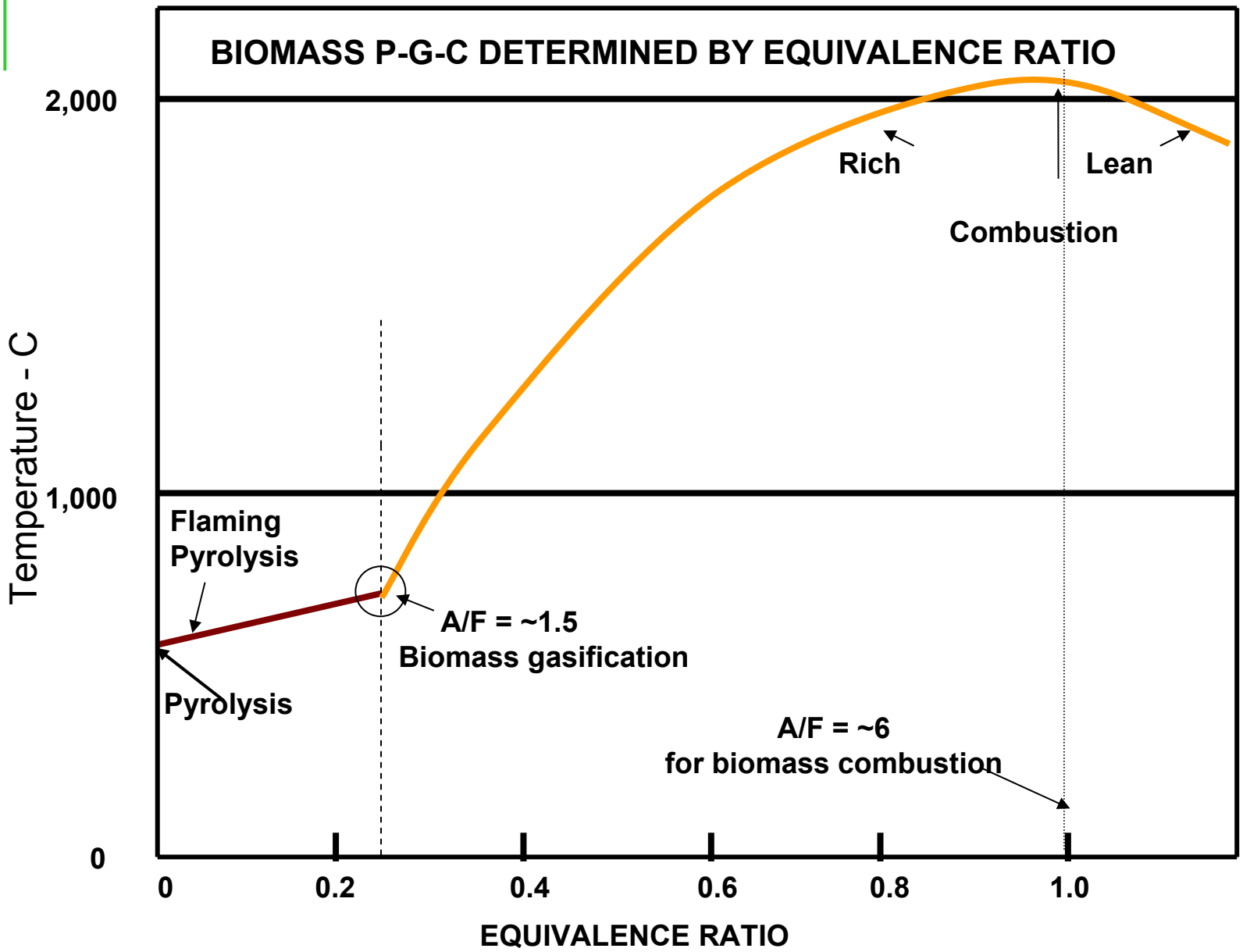
- "Combustion" is the complete conversion of the chemical energy in a fuel to heat for making heat or power
- Air is the principle ingredient for combustion, but unknown to the public - they focus on fuels and $$
- 1 kg gasoline + 15 kg air➔ complete combustion

IMPORTANCE OF THE AIR/FUEL RATIO

- The air/fuel ratio determines
  - Pyrolysis
  - Gasification
  - Clean combustion
  - Efficient combustion
  - Lean combustion
  - Rich combustion
- AND THEIR OPPOSITES

THE A/F EQUIVALENCE RATIO

- The A/F ratio for combustion is different for every fuel
  - Gasoline – 14.7 kg air/kg fuel
  - Ethanol – 9 kg air/kg fuel
  - Biomass – 6 kg air/kg fuel
  - Hydrogen – 40 kg air/kg fuel
- The equivalence ratio is the same for all fuels for combustion, gasification and “pyrolysis”
- $ER = (A/F)/(A/F)_{complete\ combustion}$


BIOMASS P-G-C DETERMINED BY EQUIVALENCE RATIO
2,000
1,000
0
Temperature - C
Rich
Lean
Combustion
Flaming
Pyrolysis
A/F = ~1.5
Biomass gasification
Pyrolysis
A/F = ~6
for biomass combustion
0
0.2
0.4
0.6
0.8
1.0
EQUIVALENCE RATIO

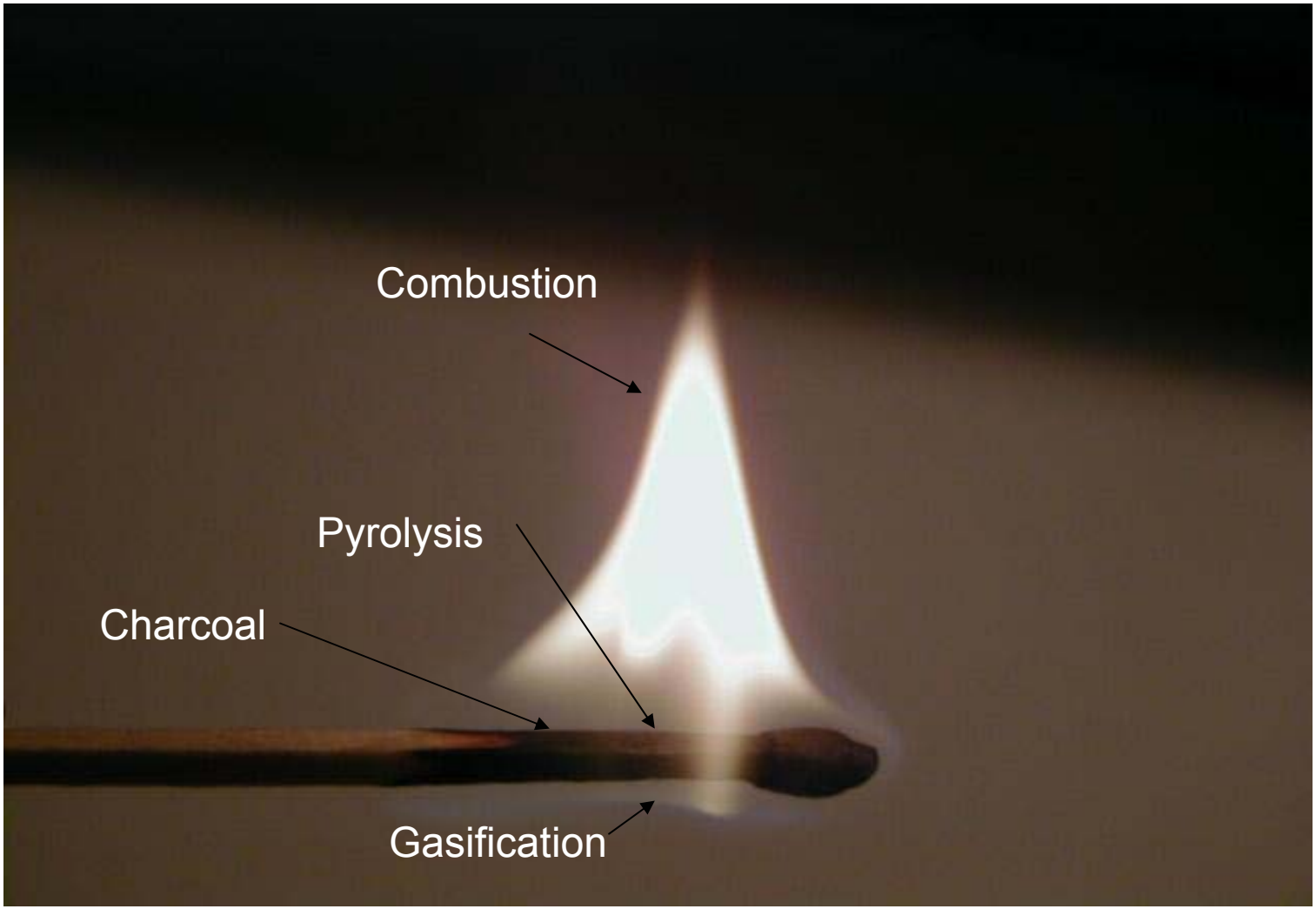
PYROLYSIS

- "Pyrolysis" is the breakdown of biomass by heat to form
  - Gases
  - volatile liquids
  - and charcoal, all good fuels
- "Pure pyrolysis" requires an external heat source and heat exchange
- "Flaming pyrolysis" burns a small amount of the volatiles to generate the heat for pyrolysis in beds of fuel or a match

GASIFICATION

- "Gasification" of biomass produces a gas
- Gases are required
  - For cleaner heat in
  - In engines, turbines, fuel cells, …
  - For synthesis of fuels and chemicals (NH3,..)
- Coal gasification was universal from 1850-1930 when natural gas pipelines were developed

C-G-P OCCUR IN THE BURNING MATCH



APPLICATION TO STOVE DESIGN

- Consider that each kG of wood can generate 20 MJ of heat
- It takes 6 kg of air to burn each kg of wood
- Wood burns in two stages – initially the volatiles burn, then the charcoal
- Wood is difficult to burn cleanly because it can't be mixed with air

APPLICATION TO WOODSTOVE DESIGN

- It takes ~1/2 to 1 1/2 kg of air to make 2 kg of WoodGas
- It takes 5 kg of air to burn each kg of WoodGas
- WoodGas burns much cleaner than wood because it can be mixed with optimum air

The WoodGas Cookstove

OTHER APPLICATIONS OF BIOMASS PGC

- Power generation from biomass
- Liquid fuels from biomass
- Home heating
- Industrial heating
  - GO FOR IT! … Thank you