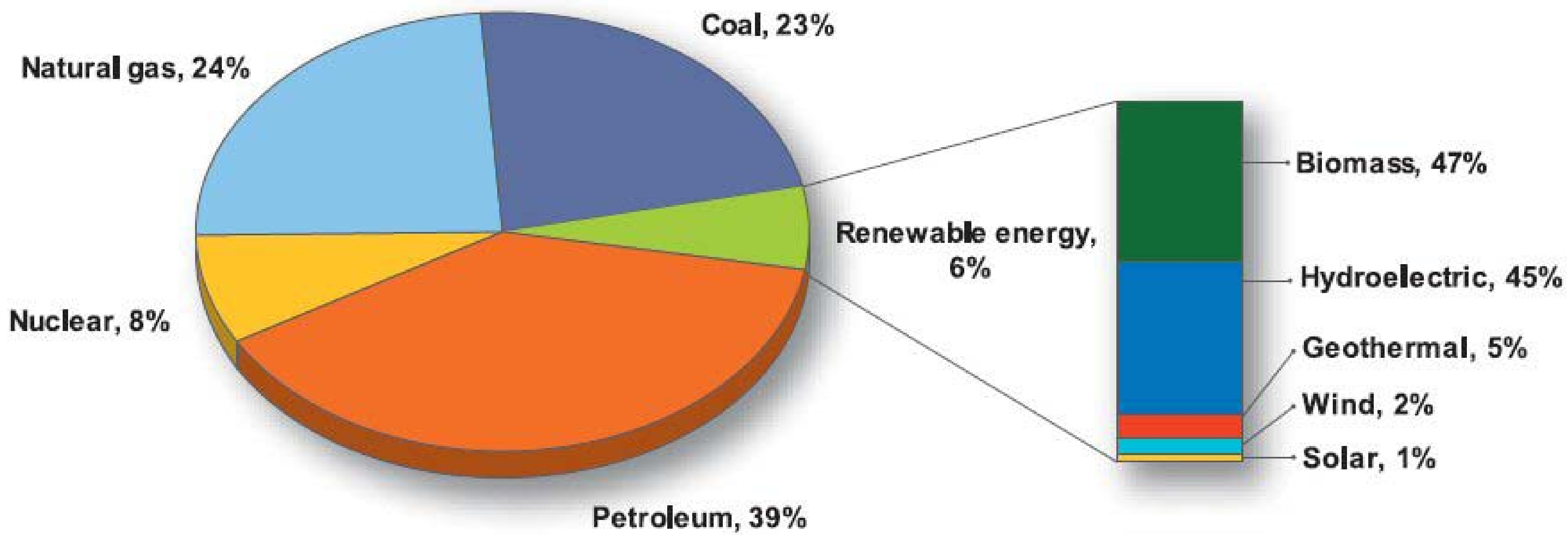
Wood Gasification

Renewable Energy Training Center

Overview – Wood Gasification

- Renewable fuel resources: Wood/biomass
- Utilization of wood resources: sustainability
- Conversion methods/processes/technologies
- What is gasification? Pyrolysis? Combustion?
- Gasification applications: past, present, future
- Intro: The woodgas camp stove
- Optional topics/concepts: thermodynamics, efficiency, energy density

U.S. Energy Sources



...a fossil-fuel dependent country (>85%)!

Source: (2005) http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

Why use wood as a fuel?

Define: Renewable Energy

- **Renewable Energy:**
  - Energy flows which are replenished at the same rate that they are used
  - Sources that are continuously replenished by natural processes
- **Q: Are all renewable energy sources sustainable?**

Sustainable Energy Defined

- An energy source that:
  - Isn't significantly depleted by continued use (i.e., renewable resource),
  - Doesn't cause significant pollution or other environmental problems, and
  - Doesn't perpetuate significant health hazards or social injustices

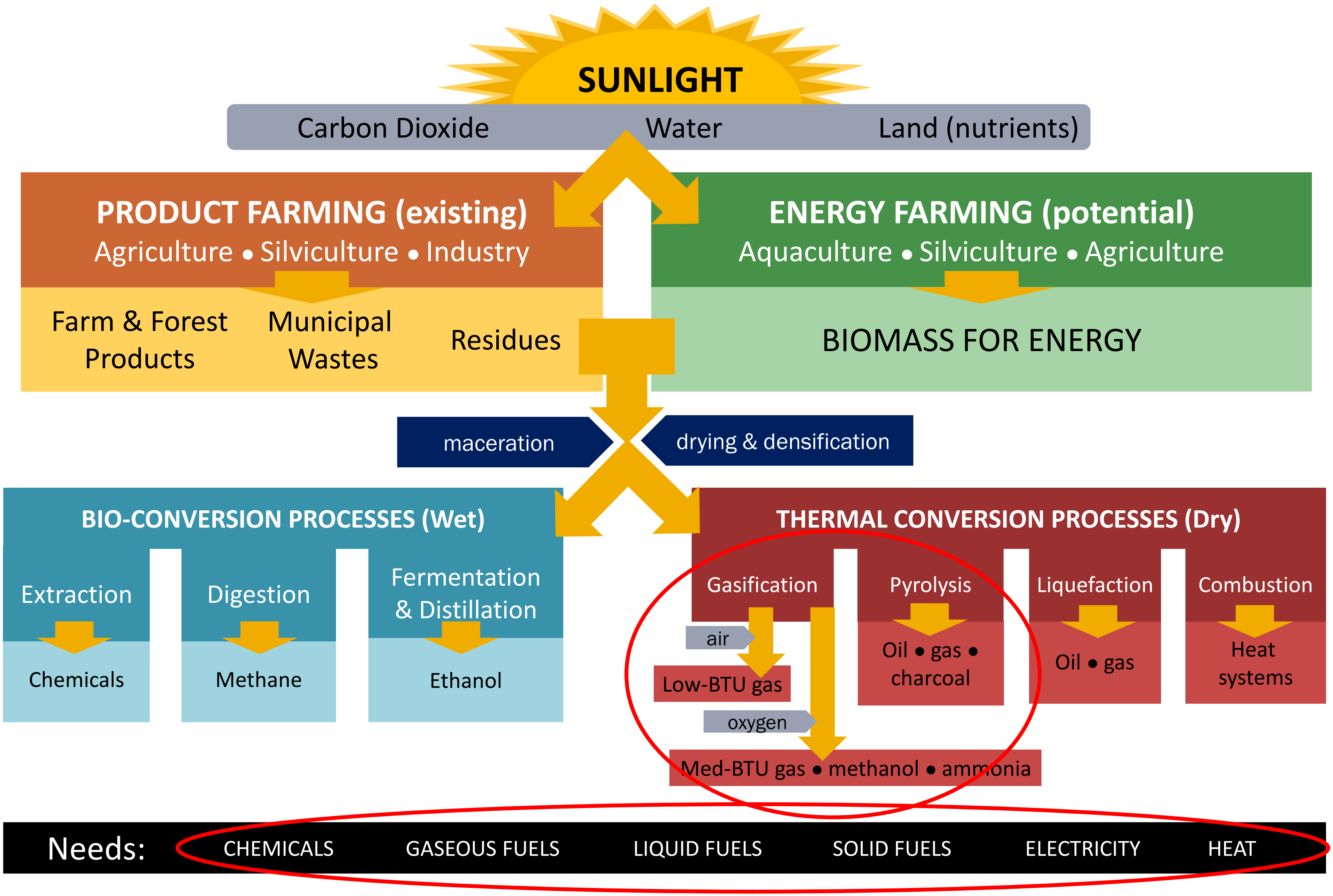
(Boyle 2004)

The Fuel Resource: Biomass

- Living matter (dead or alive); any organic matter which is available on a renewable or recurring basis
- A tiny, but critically important % of earth's matter.
- For humans, an enormous energy supply.
- Continually replenished by: the **SUN**
- Through the process of:

P H O T O S Y N T H E S I S

Paths of Biomass Energy Conversion



(adapted from: Solar Energy Research Institute, 1988)

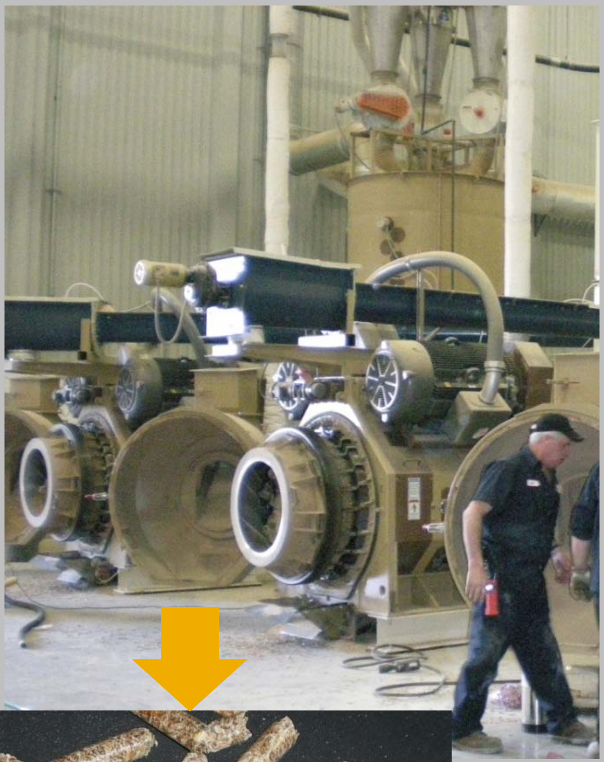
Fuel Sources: Low-grade wood

Photo by: B. Ballard

Dedicated Bioenergy Crops

Photo by: B. Ballard

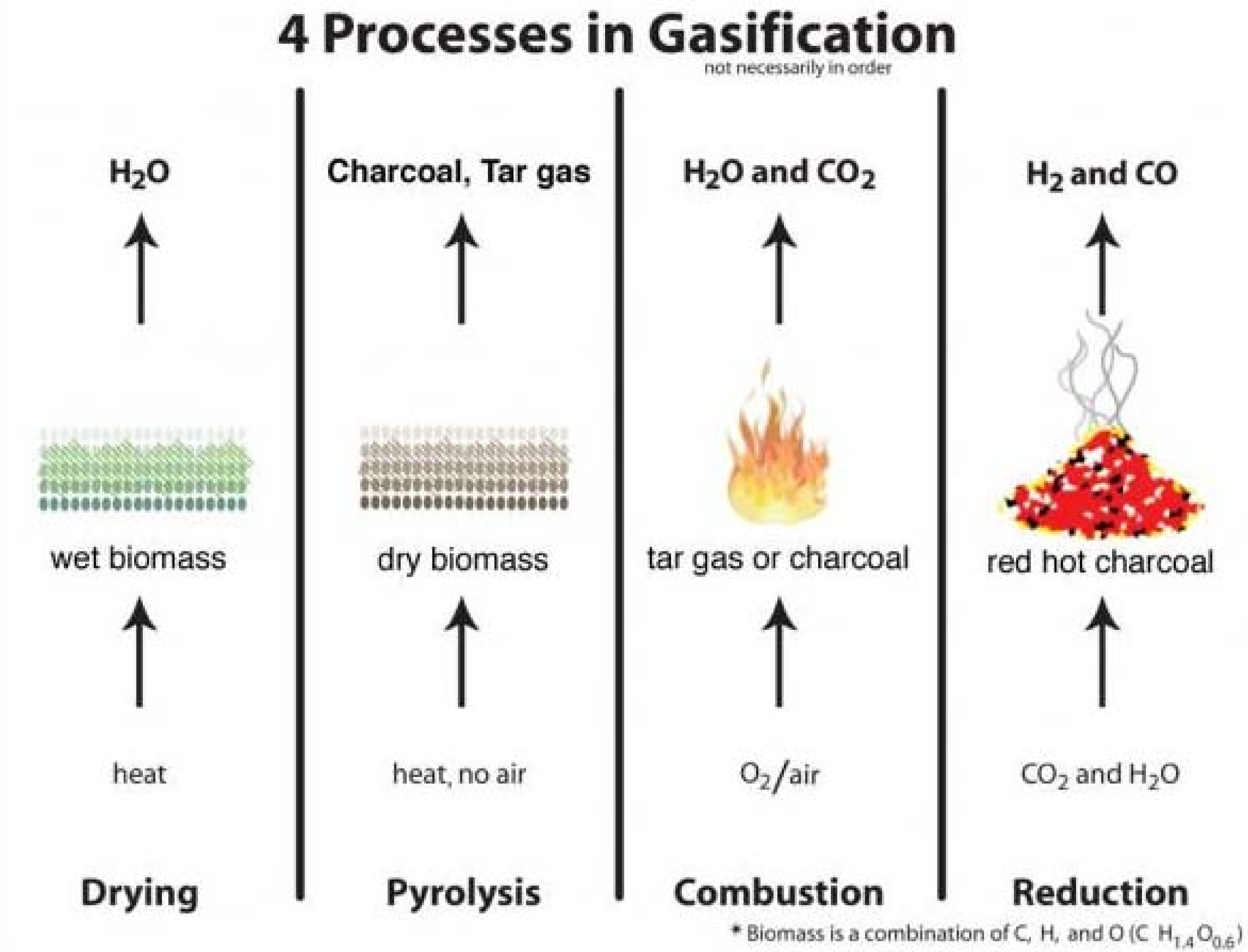
Feedstock for gasifiers: wood pellets



Photos by: B. Ballard

What is gasification?

- A process that converts carbon-based materials (e.g., wood/biomass) into combustible gases (principally $CO + H_2$) by reacting the solid fuel at high temperatures with a controlled (limited) amount of oxygen



(Source: Jim Mason - http://gekgasifier.com/forums/album.php?albumid=2&pictureid=3)

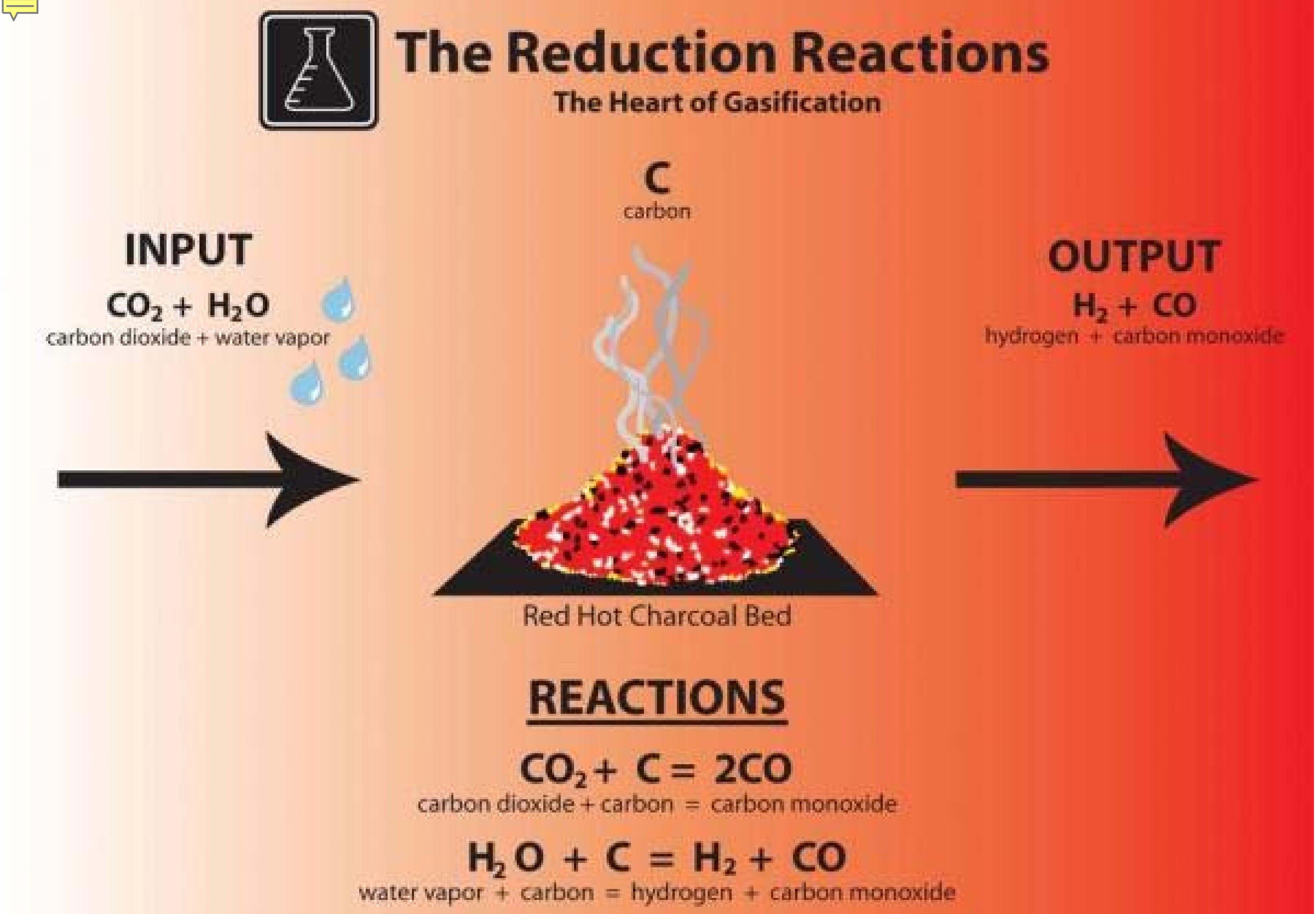
What is combustion?

Fuel + Oxygen → HEAT + Water + Carbon dioxide

$C_3H_8 + 5O_2 \rightarrow$ HEAT + $4H_2O + 3CO_2$

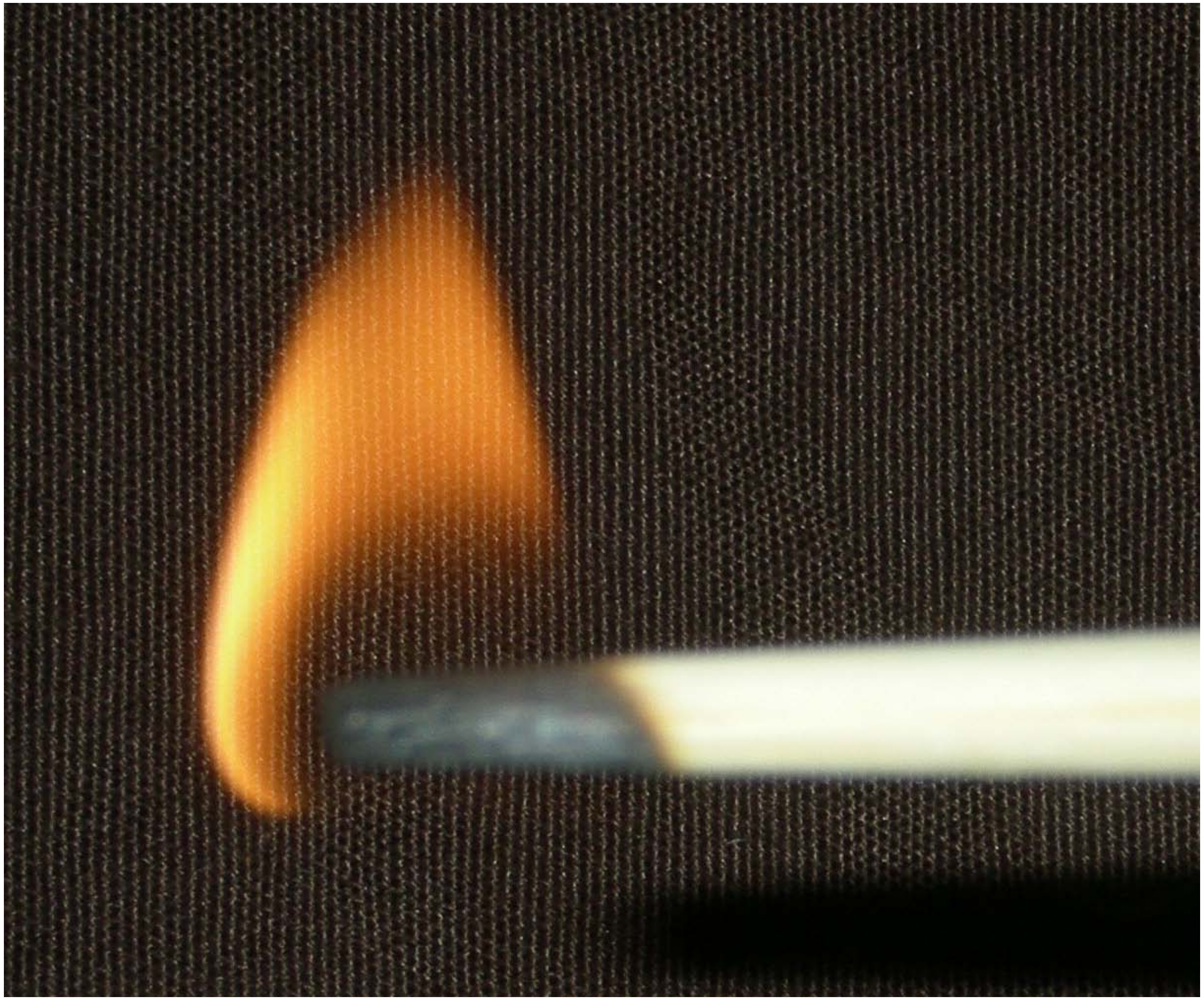
Limit O_2 → HEAT + H_2O + CO_2 + ($CO + H_2$)

(both combustible)



(Source: Jim Mason - http://gekgasifier.com/forums/album.php?albumid=2&pictureid=1)

What is combustion?



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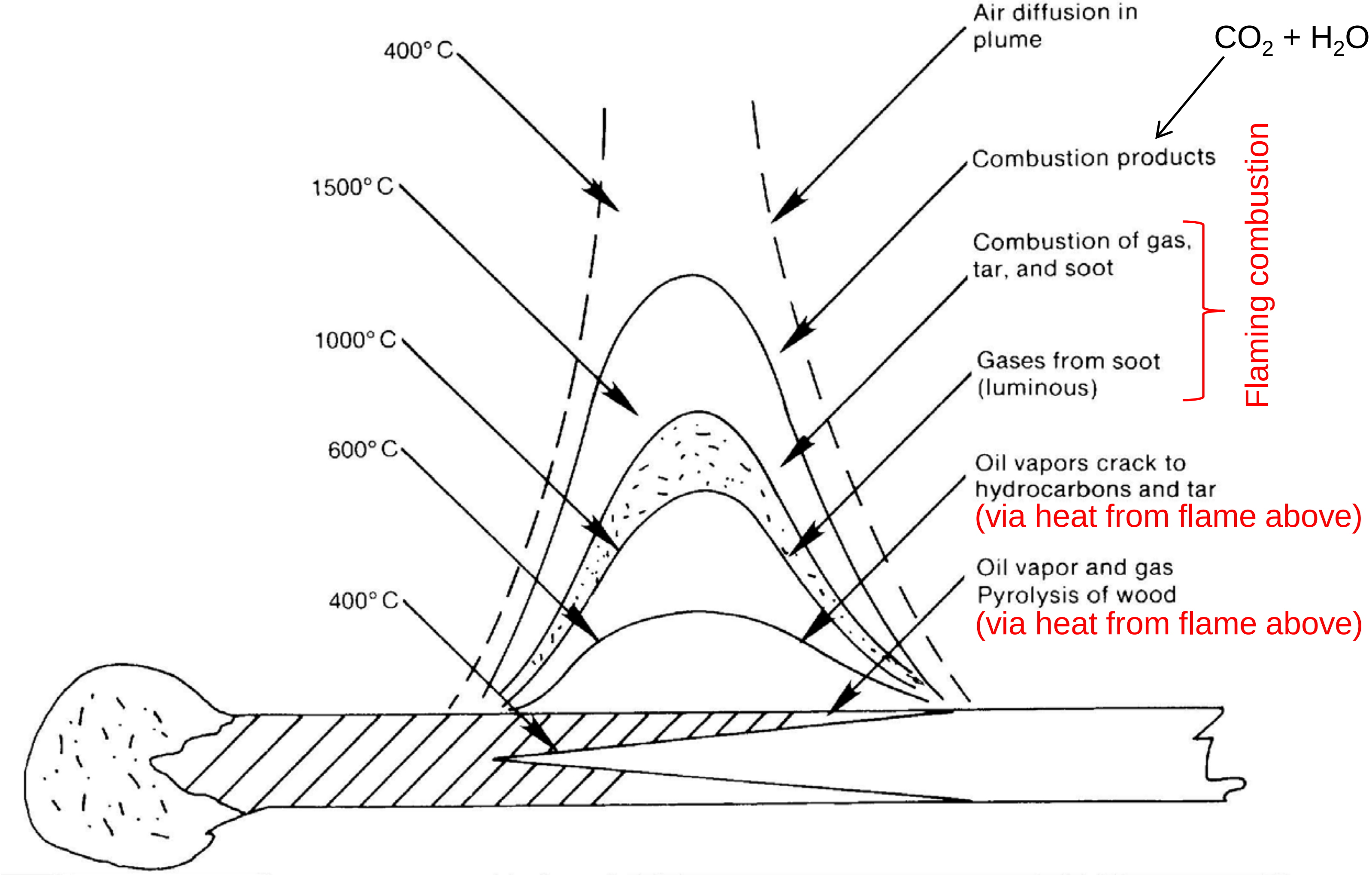
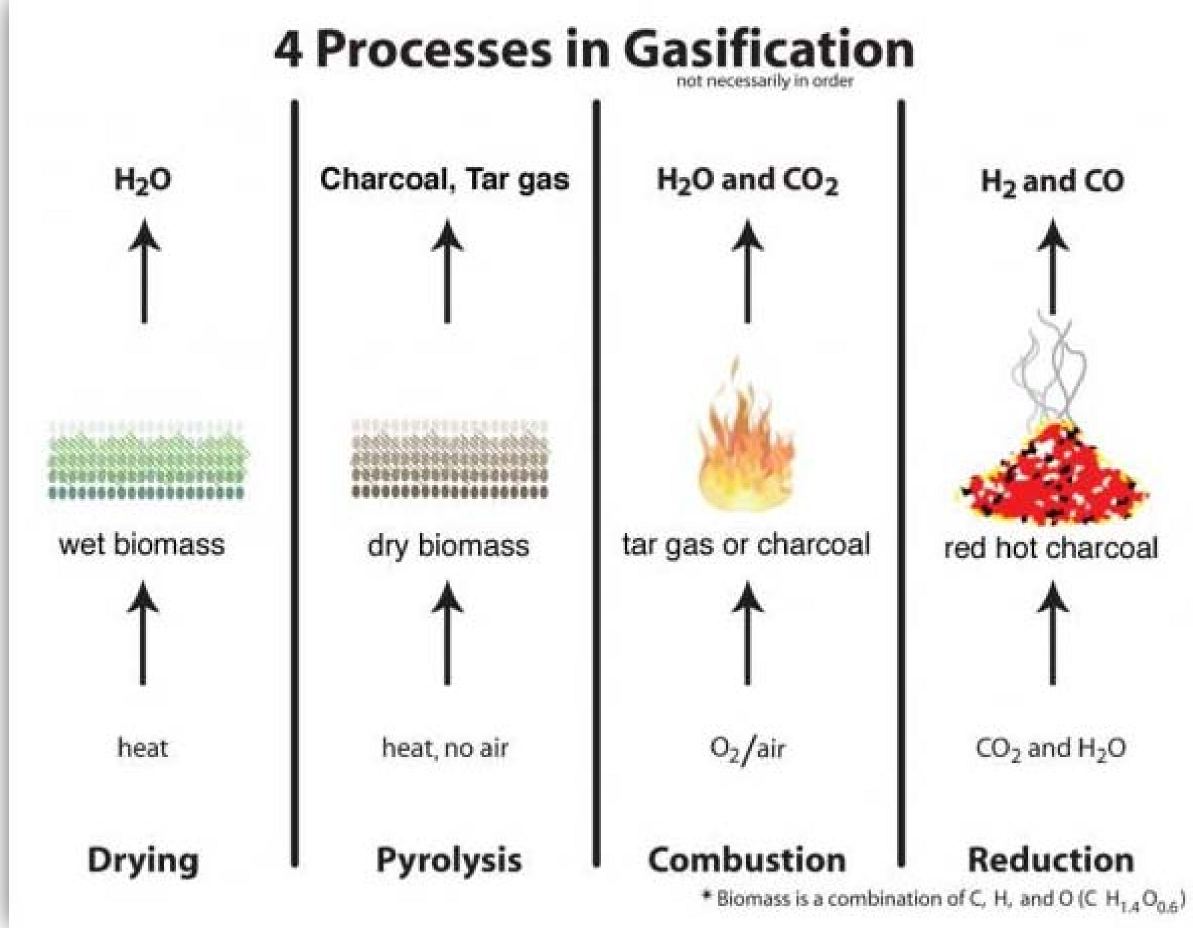


4-2. *Pyrolysis, gasification, and combustion in the flaming match*

(Solar Energy Research Institute, 1988)

What is gasification?

- Gasification is a thermo-chemical process, where heat converts solid biomass into flammable gases.



(Source: Jim Mason - http://gekgasifier.com/forums/album.php?albumid=2&pictureid=3)

What is gasification?

Gasification consists of four processes:

1. **Drying** - by using heat (supplied by burning some of the wood), water evaporates from the wood.

2. **Pyrolisis** - above 270°C (heat supplied by burning some of the wood) the wood structure breaks apart chemically. Long molecules are made smaller. Charcoal/char and tar-oil gases are created.

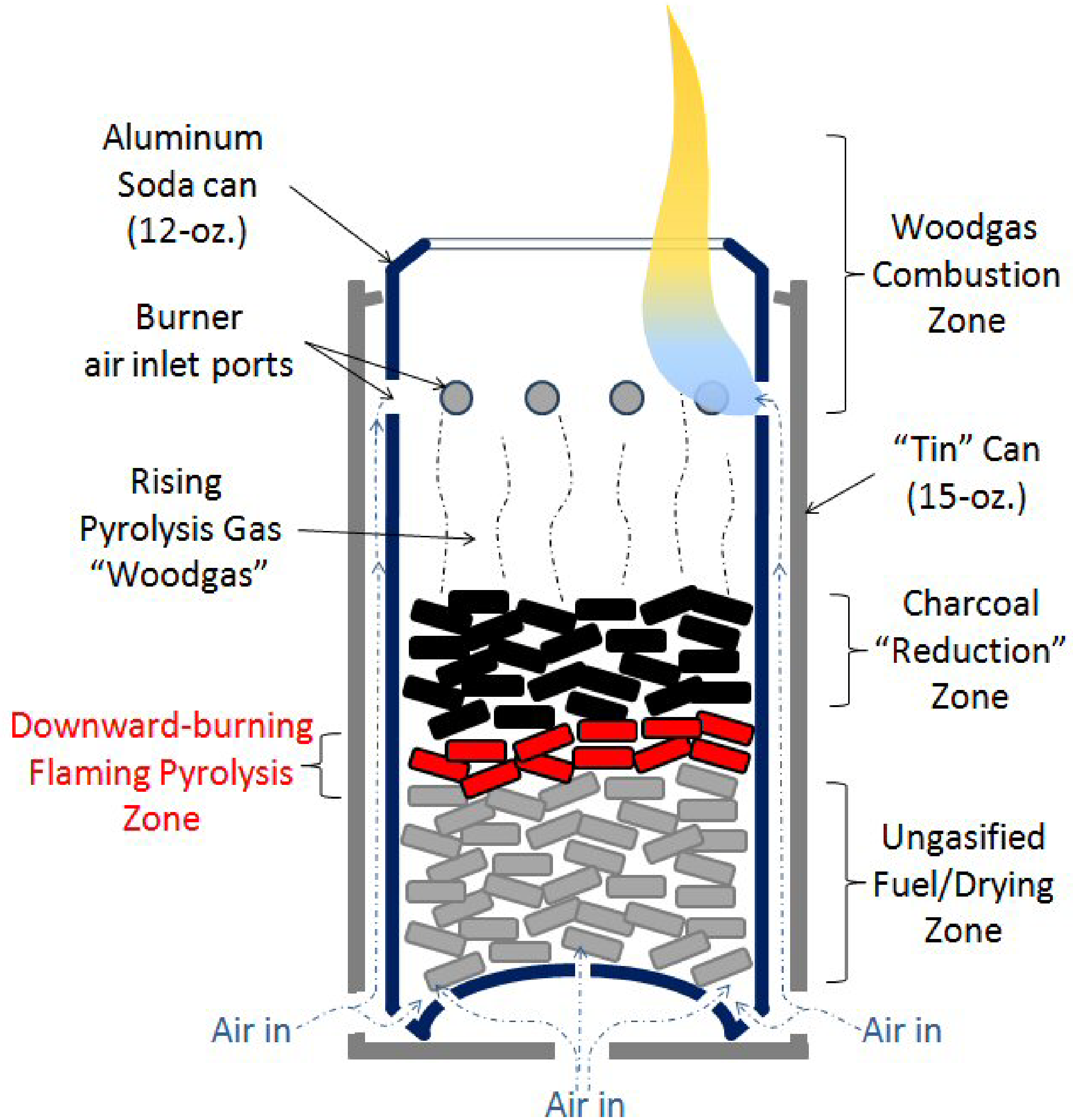
What is gasification?

3. **Combustion (oxidation)** – (with a limited/controlled supply of air, this process is also referred to as "flaming pyrolysis" in a gasifier)
   - part of the carbon (char) is oxidized (burned) to form carbon dioxide (CO_2), and
   - Hydrogen (H) is oxidized to form water (H_2O).
   - A lot of HEAT is released (temperatures up to 1400°C !). This heat is necessary for the next step…

What is gasification?

4. **Reduction -** In the reduction area several key conversions take place, and these require significant HEAT
   - **Carbon (char) reacts with CO_2 and converts it to carbon monoxide (CO).**
   - **Carbon also reacts with H_2O, "stealing" an oxygen atom producing carbon monoxide and hydrogen gases.**
   - Some of the char (C) also binds with H to create methane, and some CO reacts with H to form methane + water.

Gasification Reaction Zones



What is woodgas?

Typically woodgas consists of:

- 22% carbon monoxide (CO)
- 18% hydrogen (H_2)
- 3% methane (CH_4)
- 6% carbon dioxide (CO_2)
- 51% nitrogen (N_2)

.

Gasification Applications

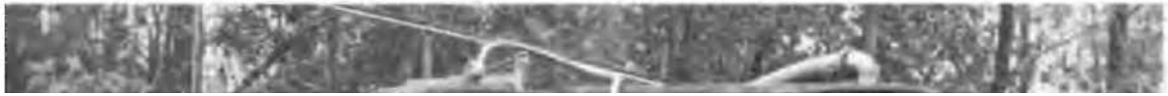
- Gasification is not a newly discovered process…
- It was used in the past for heating, lighting, and vehicle fuel.
- During World War II over a million gasifiers were in use!

Wood Gasification: Mobile Apps.

- Vehicle modifications included:
  - 1) a gas generator, 2) a gas reservoir, and 3) carburetor modifications and additional plumbing to convey, filter, and meter the gas into the engine

Daimler-Benz, Germany

Wood Gasification: Mobile Apps.



Hearse, Australia

Madison, Wisconsin, USA, 1943. Truck fueled by sawdust. (Forest Products Laboratory, US Forest Service)

(Source: National Academy of Sciences, 1983)

Construction of a Simplified Wood Gas Generator for Fueling Internal Combustion Engines in a Petroleum Emergency (book produced by the Federal Emergency Management Agency, 2nd ed. 1989)

Wood Gasification: Mobile Apps.

- Some interesting, more recent conversions…some very nice looking…lots of stainless steel: http://woodgas.nl/GB/woodgasification.html

Other Woodgas Applications

- Half of humanity cooks over wood fires
- Nearly half the world's wood supply is used as fuel.
- PROBLEMS: Wood fires cook slowly, the smoke causes glaucoma and lung diseases, fires can burn children, fires burn too much fuel, requiring that wood be gathered from greater and greater distances.

Small Stationary Applications

- **A Wood-gas Stove For Developing Countries**
  (Reed and Larson, 1996)
  - 300g (0.7 lbs.) of sticks or chips burn for 30-45 minutes at high efficiency with low emissions

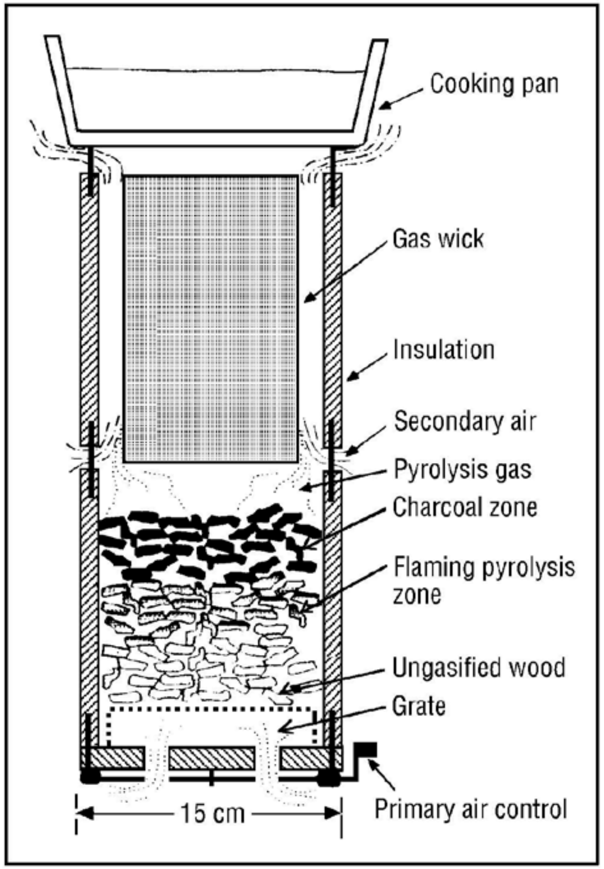


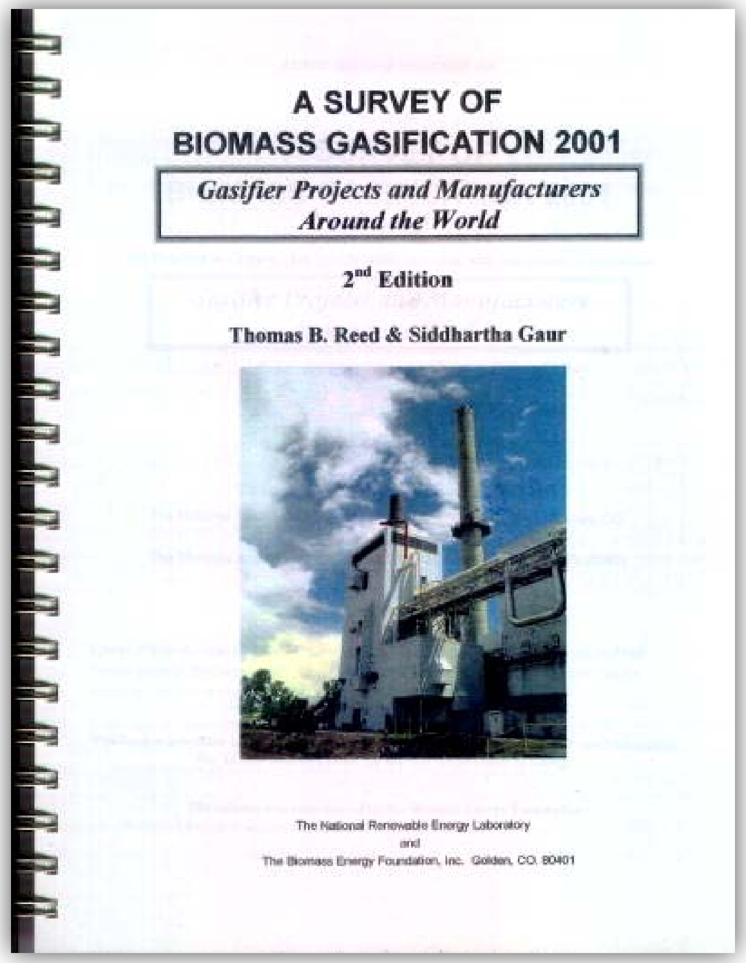
Figure 1. Wood-gas cooking stove showing lower gasifier section, upper burner section and pan heating.

Gasification Experimenter's Kit (GEK)

- Experimentation at a larger scale than a woodgas camp stove…
- Stationary or mobile applications
- "Open source" engineering project developed and maintained by ALL Power Labs in Berkeley, CA
- http://www.gekgasifier.com/

Large-scale Gasification Applications

- Large gasifiers can be fixed bed (updraft or downdraft) or fluidized bed gasifiers.
- Large quantity of biomass (e.g., MSW): a 100 ton/day unit would yield about 20 $MW_{thermal}$ or about 4 Mw_{el} (at 20% efficiency of thermal to electric)
- BUT, expensive: $10M ($2000/kW capacity)



http://www.woodgas.com/small_gasifiers.htm

Biomass Gasification

- Conversion efficiencies vary depending on the size and sophistication of the system used
  - Some applications are 80-90% (e.g., wood gasification boilers)
- Large-scale gasification plants have not proven financial viability (yet)
- BUT, the potential exists for production of:
  - Electricity from biomass-fed gas turbines
  - Liquid fuels (methanol, Fischer Tropsch diesel) as petroleum substitutes
  - Hydrogen or other fuel for fuel cells

Why is gasification important?

Benefits include:

- Gasification technologies are typically **more efficient** than traditional combustion technologies. No SMOKE!
- Gaseous fuel can be produced from a solid fuel, resulting in a potentially **more versatile** fuel
- Small- to large-scale applications
- Mobile or stationary applications

Woodgas Camp Stove "Lab"

- Build and test a woodgas stove

Other concepts to incorporate/consider

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Abundant, renewable vs. Energy Dense?

- Biomass is a great renewable energy source.
- However, it is typically not a good (unprocessed) fuel, because it often contains more than 70% air/void space.
- This results in a low **volumetric energy density** makes it difficult to collect, ship, store and use.

Biomass Energy Density

FUEL	Bulk Density (kg/liter)	Mass Energy Density (MJ/kg)	Volume Energy Density (MJ/liter)
Softwood chips (“Denver dry”, 7% MCWB)	0.19	20	3.8
Coconut shell (broken to ¼” pieces)	0.54	20.5	11.1
Sawdust pellets (¼”) (Home Depot)	0.68	20	13.6
Peanut shell pellets (3/8”)	0.65	19.8	12.9
Corn	0.76	19.1	14.5
Soybeans	0.77	21 (?)	16.2
Coal (bituminous)	1.1 (?)	32.5	35.7
Biodiesel	0.92	41.2	37.9
Diesel	0.88	45.7	40.2

(Source: Gaur and Reed, Dekker, 1998)

Laws of Thermodynamics

1st Law of Thermodynamics

- In any transformation of energy from one form to another, the total quantity of energy remains unchanged (energy is always conserved)

- Why then do we say: "Turn off the lights when you leave the room. We need to conserve electricity!"?

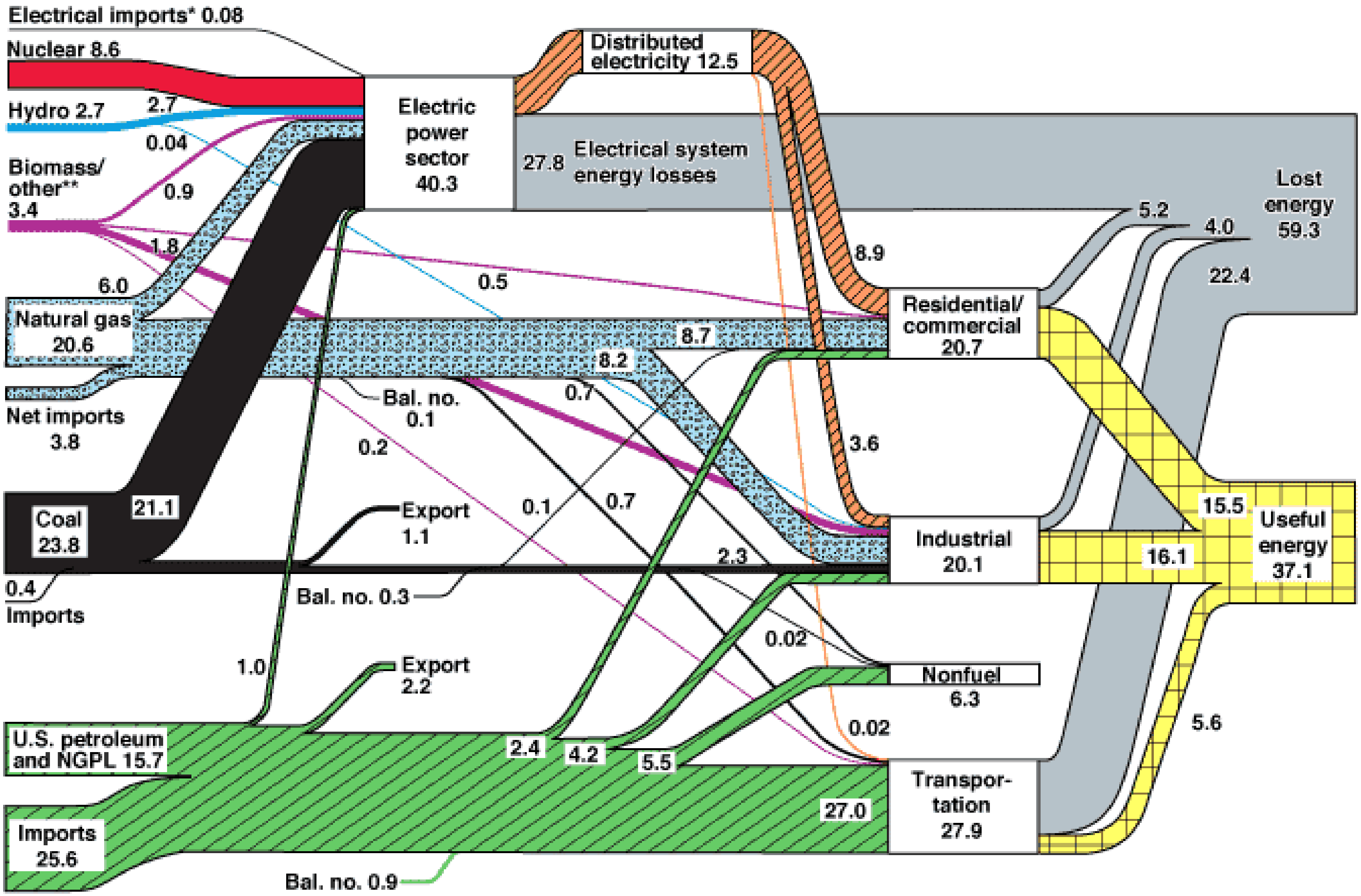
2nd Law & Conversion Efficiency

- There is a limit to the efficiency of any heat engine.
- Useful energy output < energy input
- Why?

EFFICIENCY =

(useful output)/(required input) × 100%

U.S. Energy Flow Trends – 2002
Net Primary Resource Consumption ~103 Exajoules



Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002*.
*Net fossil-fuel electrical imports.
**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

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Lawrence Livermore National Laboratory
http://eed.llnl.gov/flow

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