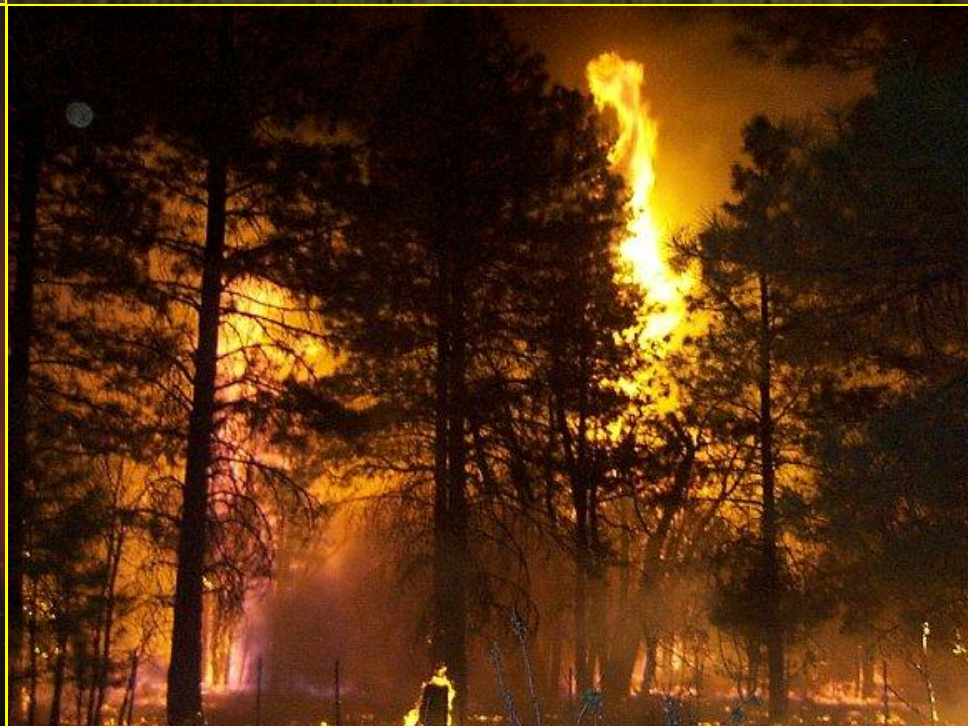


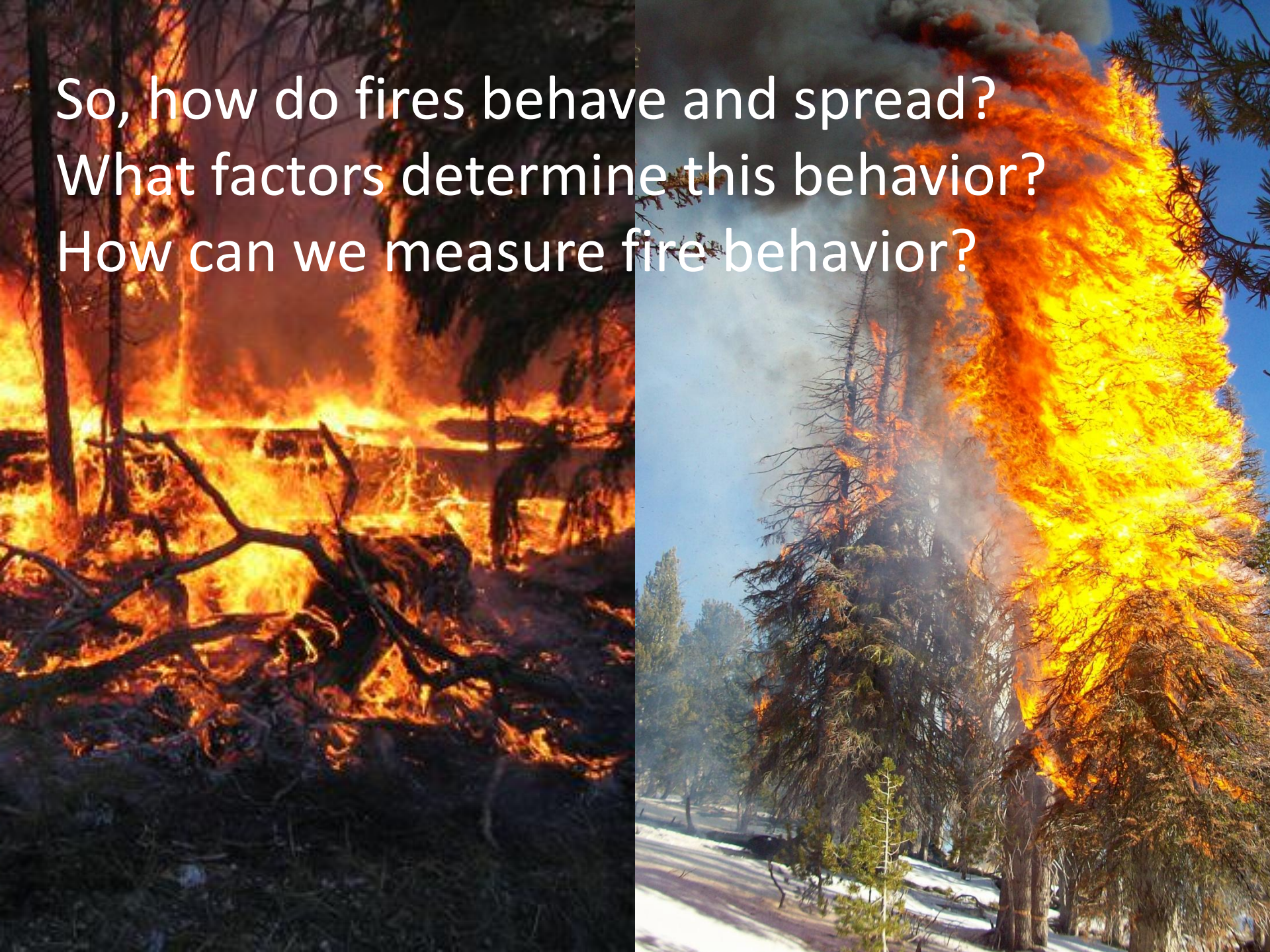



Unit 2: Fire behavior

2.1 Introduction

Fire behavior is one of the most prominent and characteristic features of wildland fire

Blowup, 2011 Las Conchas Fire, New Mexico. Photo courtesy Craig Allen, USGS.



So, how do fires behave and spread?
What factors determine this behavior?
How can we measure fire behavior?

Recall the three basic modes of energy transfer work during fire

Conduction: Heat passes through burning fuels (*e.g.* through a log or branch), driving off moisture and preparing it for burning; soil heating is mostly conductive

Convection: Heated air and gases rise above burning fuels into tree canopies, scorching and preheating them; smoke plumes are convective

Radiation: Heat radiated from a flaming front pre-heats grass, shrub, and tree fuels, causing the flaming front to move along

Recall the stages of combustion:

Phase I: Pre-heating (pre-ignition)

- Fuels ahead of the fire are pre-heated by convection and radiation
- Dehydration: Water is driven out of the fuel (so fuels become drier) ~ 100° C
- Volatiles (extractives) evaporate into gas phase
- *Pyrolysis* of solid fuels ~ 325° C
- These reactions are mostly *endothermic*

Phase II: Gas (ignition) phase

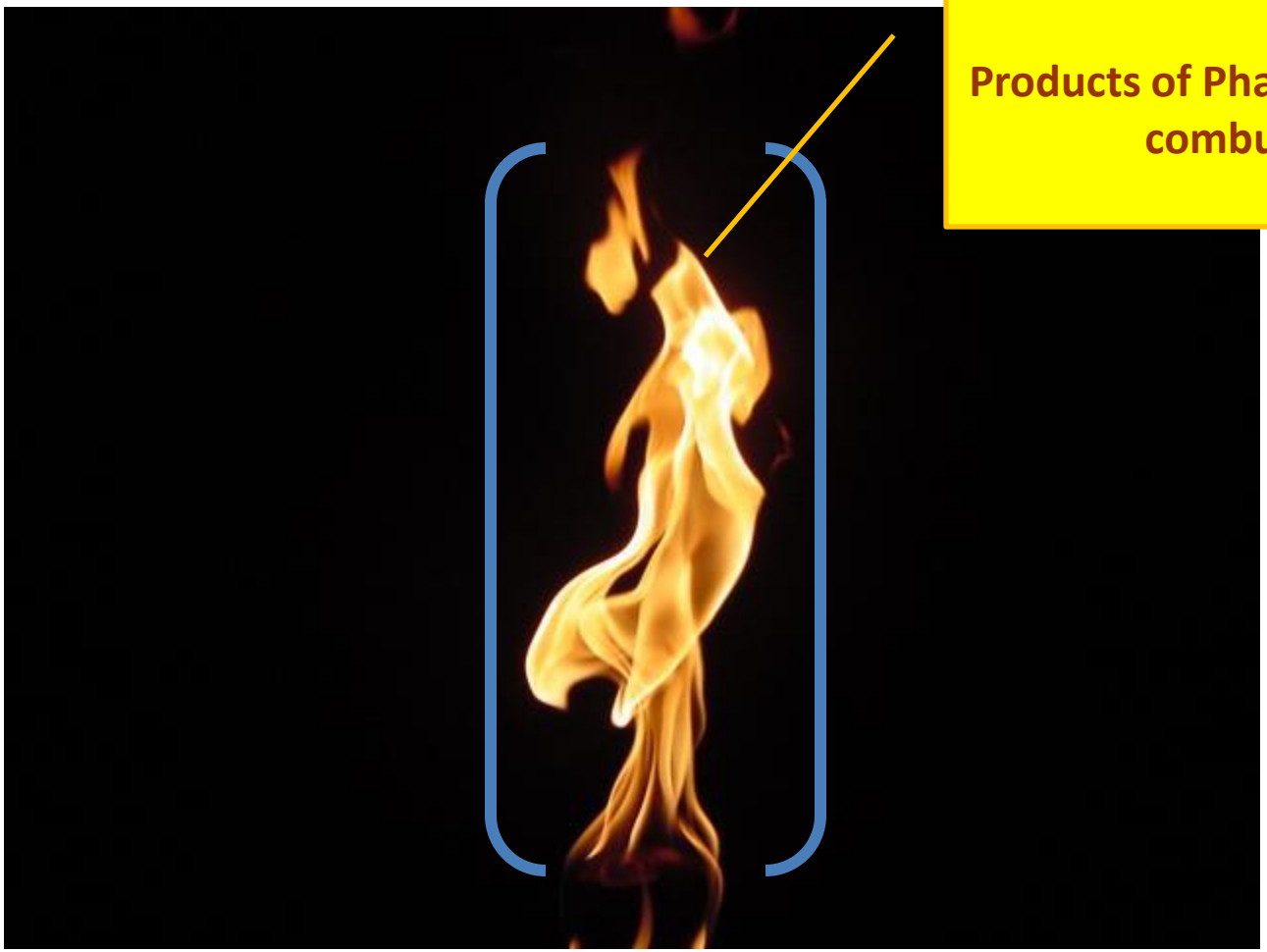
- Volatiles generated in Phase I (by evaporation and pyrolysis) ignite and oxidize
- This is when we start to see *flames*
- Phase II is ***exothermic*** – chemical bond energy is being released
- Typical wildland fire temperatures 400-1000 °C

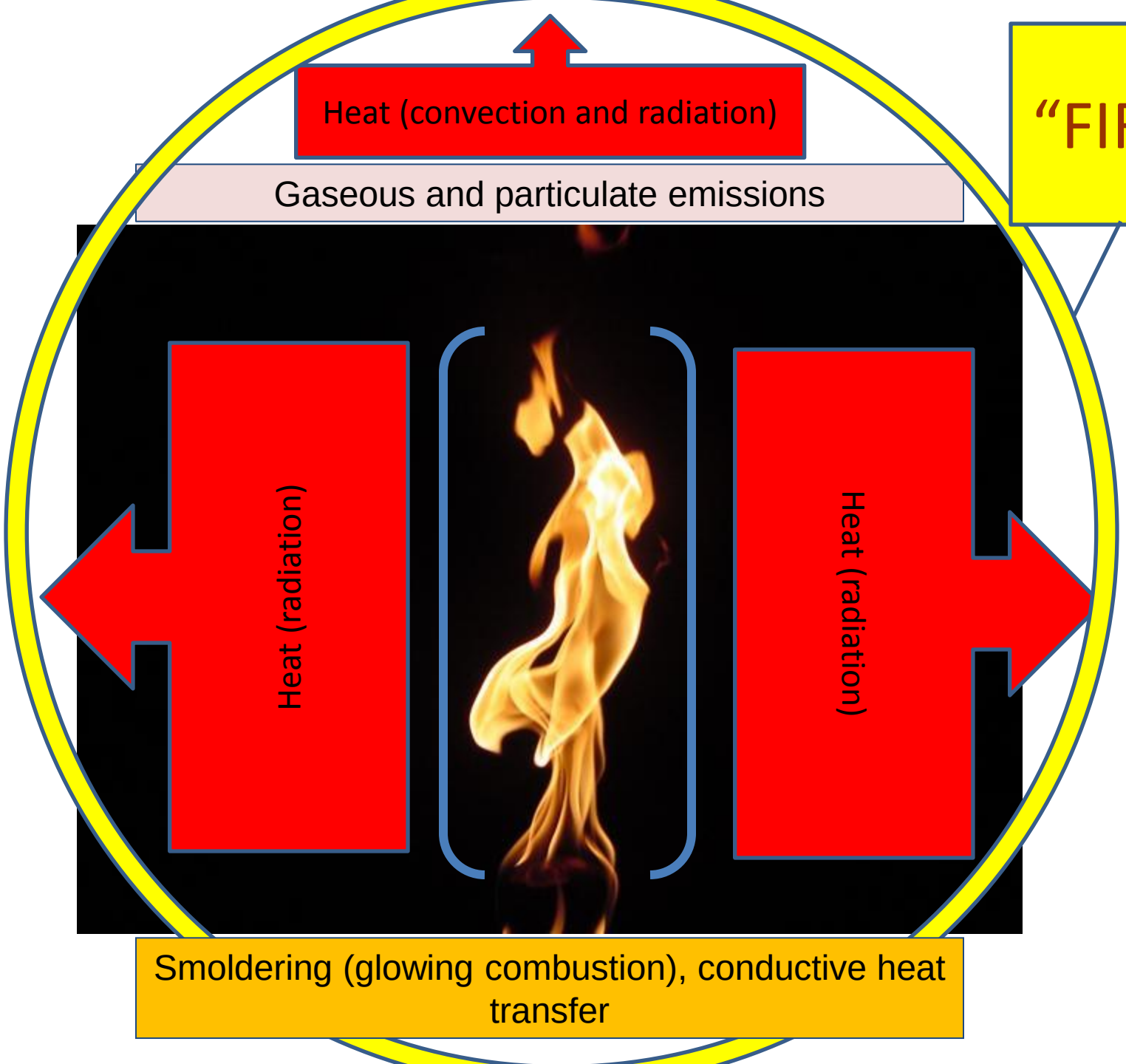
So a spreading fire is a chain reaction

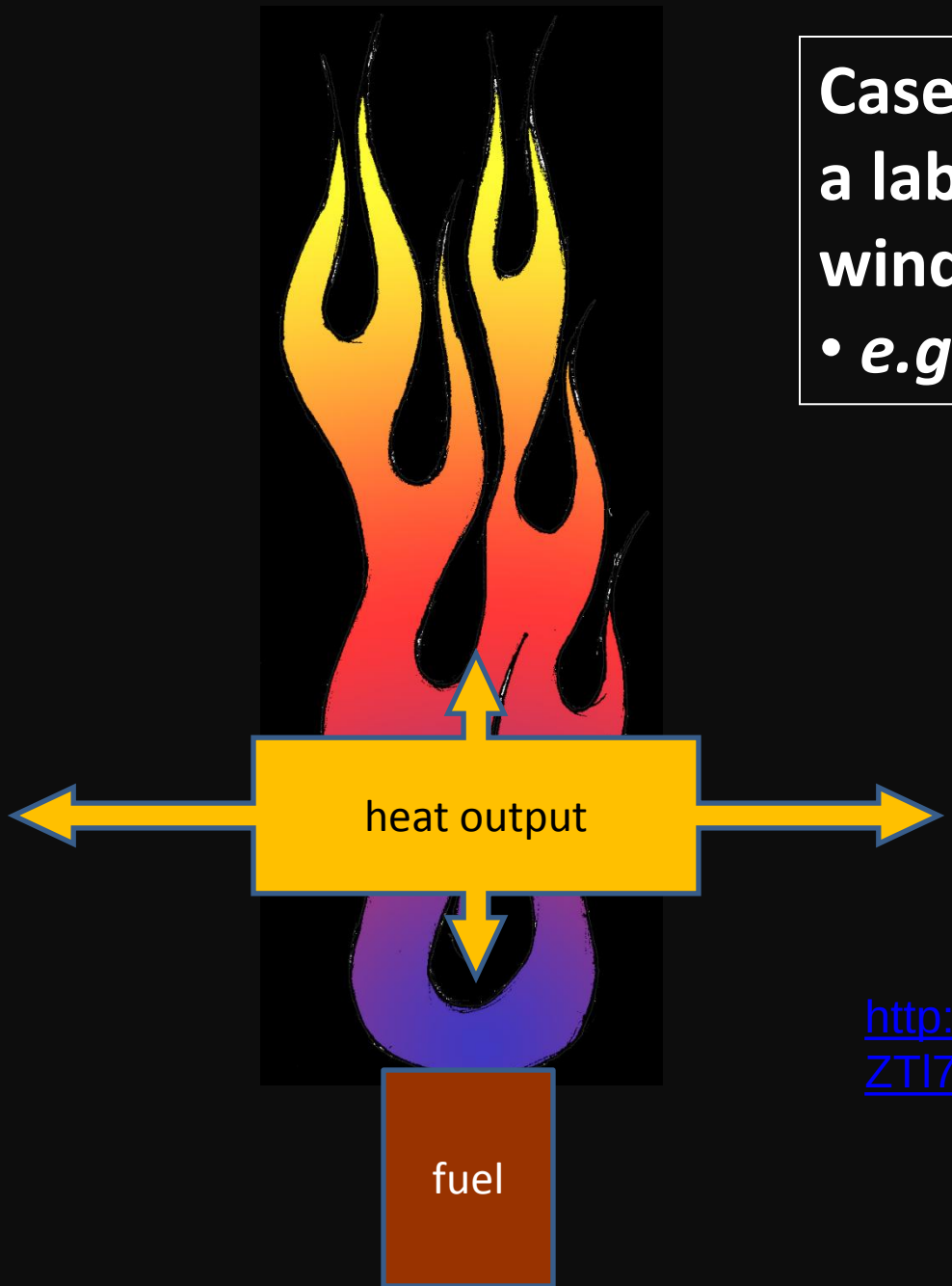
- Initiation energy begins pre-heating and pyrolysis
- The gas (ignition) and smoldering phases are exothermic (generates more energy than it consumes)
- This energy further pre-heats more fuel, keeps the reaction going
- The reaction stops when one of the legs of the combustion triangle is no longer present

What is a “flame”?

Flame: the visible (light-emitting) element of a fire




Heat (convection and radiation)
"FIRE"
Gaseous and particulate emissions
Heat (radiation)
Heat (radiation)
Smoldering (glowing combustion), conductive heat transfer



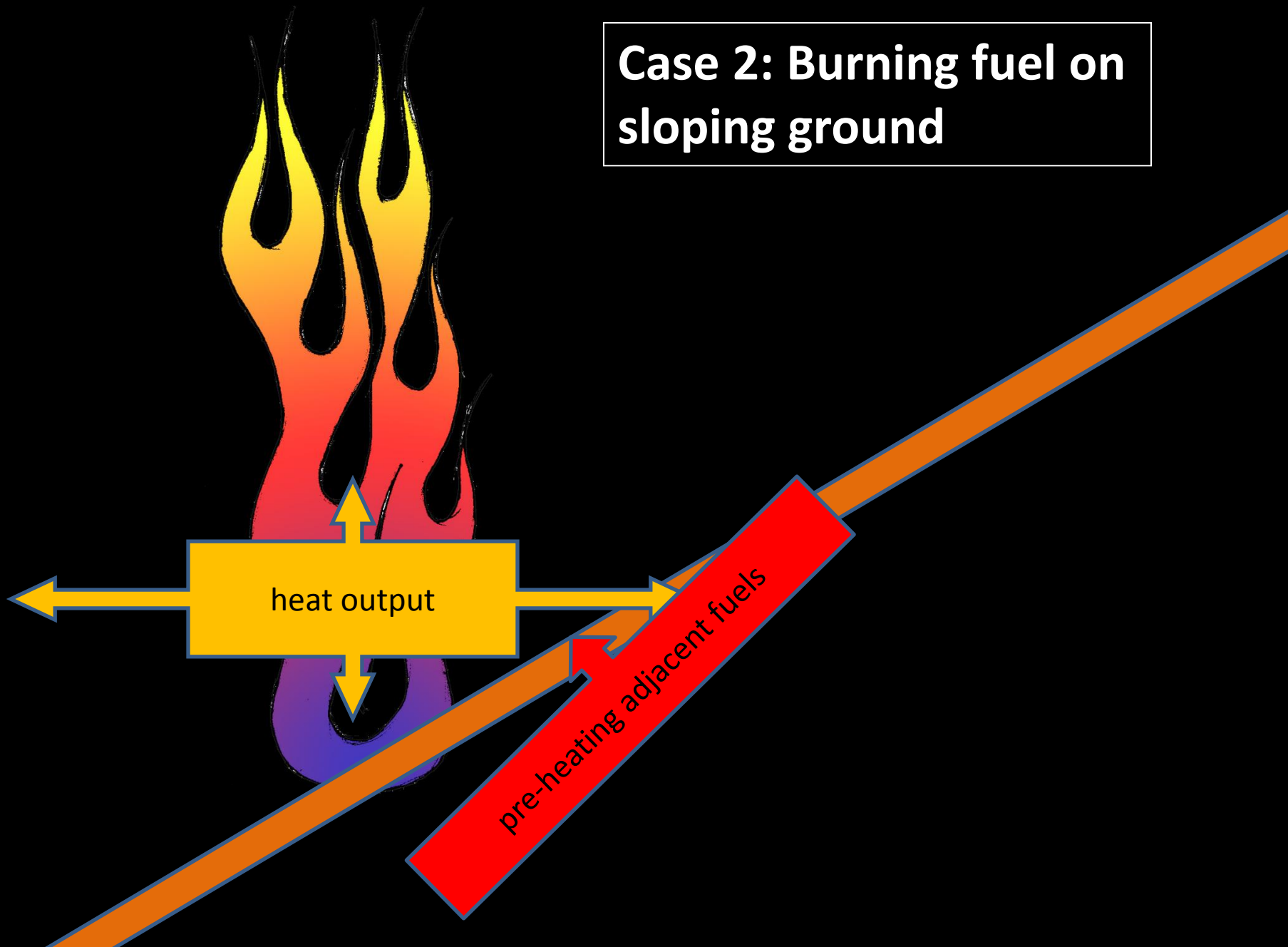
Case 1: Burning fuel in a lab (flat surface, no wind)

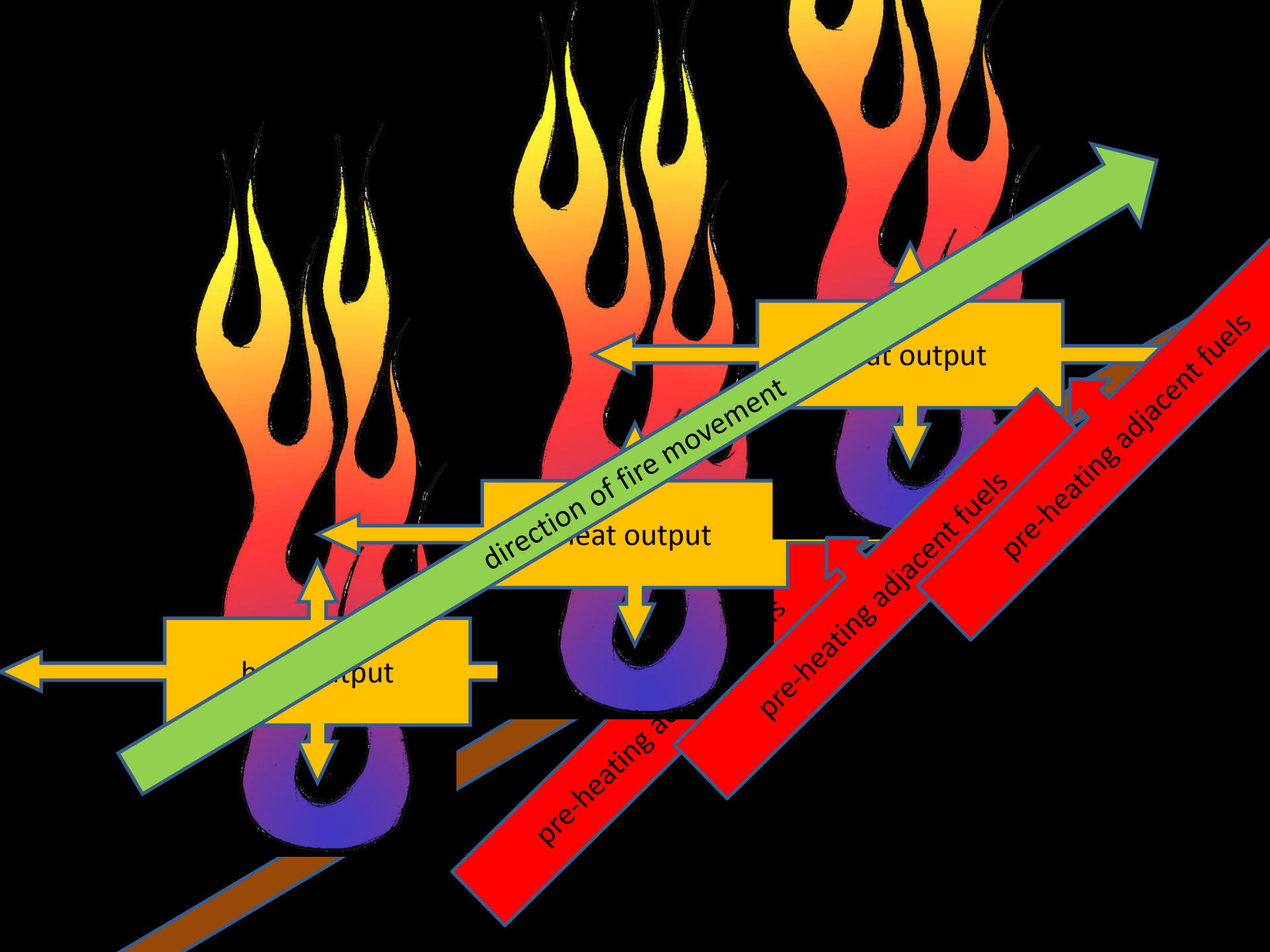
- ***e.g.*** **a candle**

What about in zero gravity?

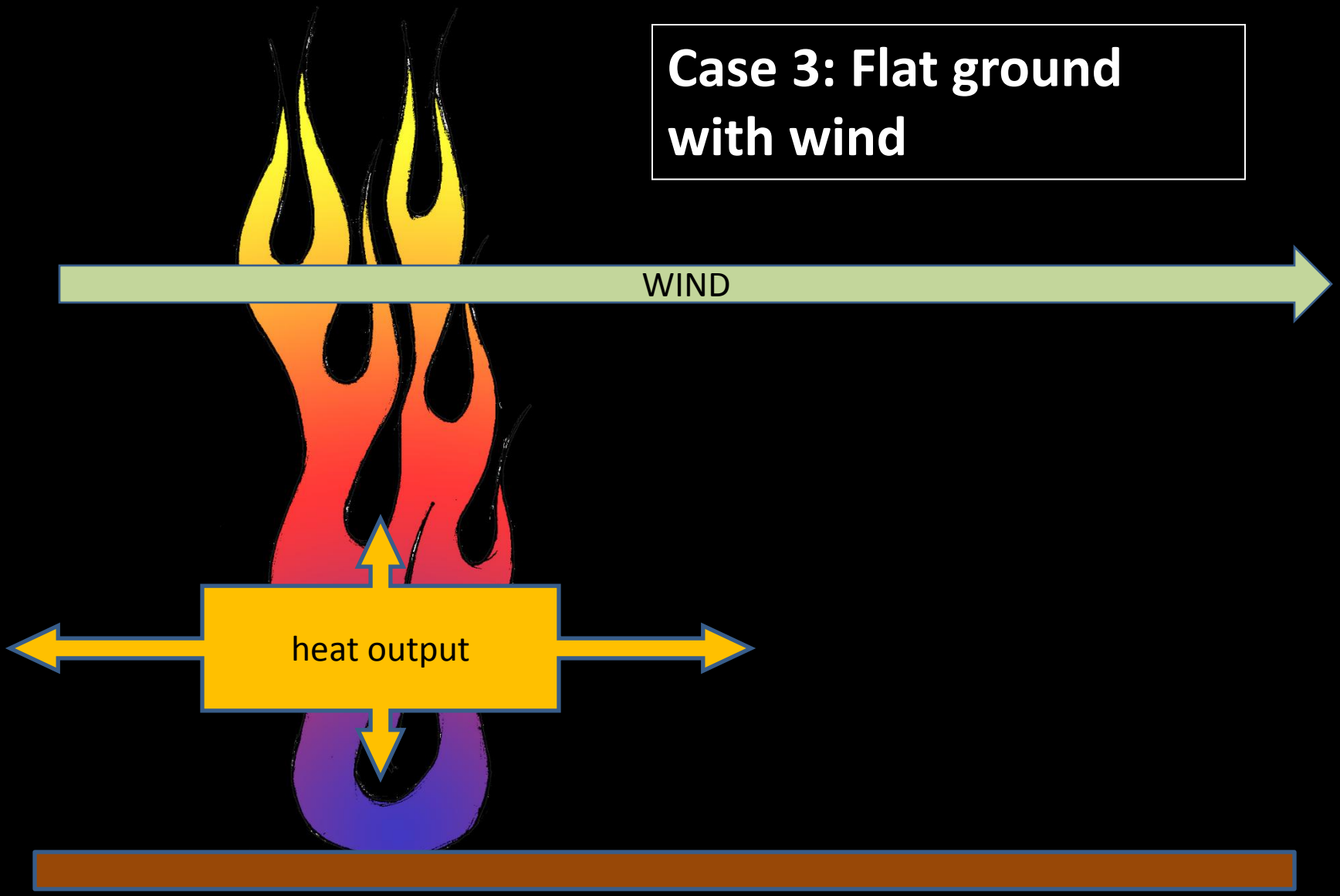
http://www.youtube.com/watch?v=SZTl7oi05dQ

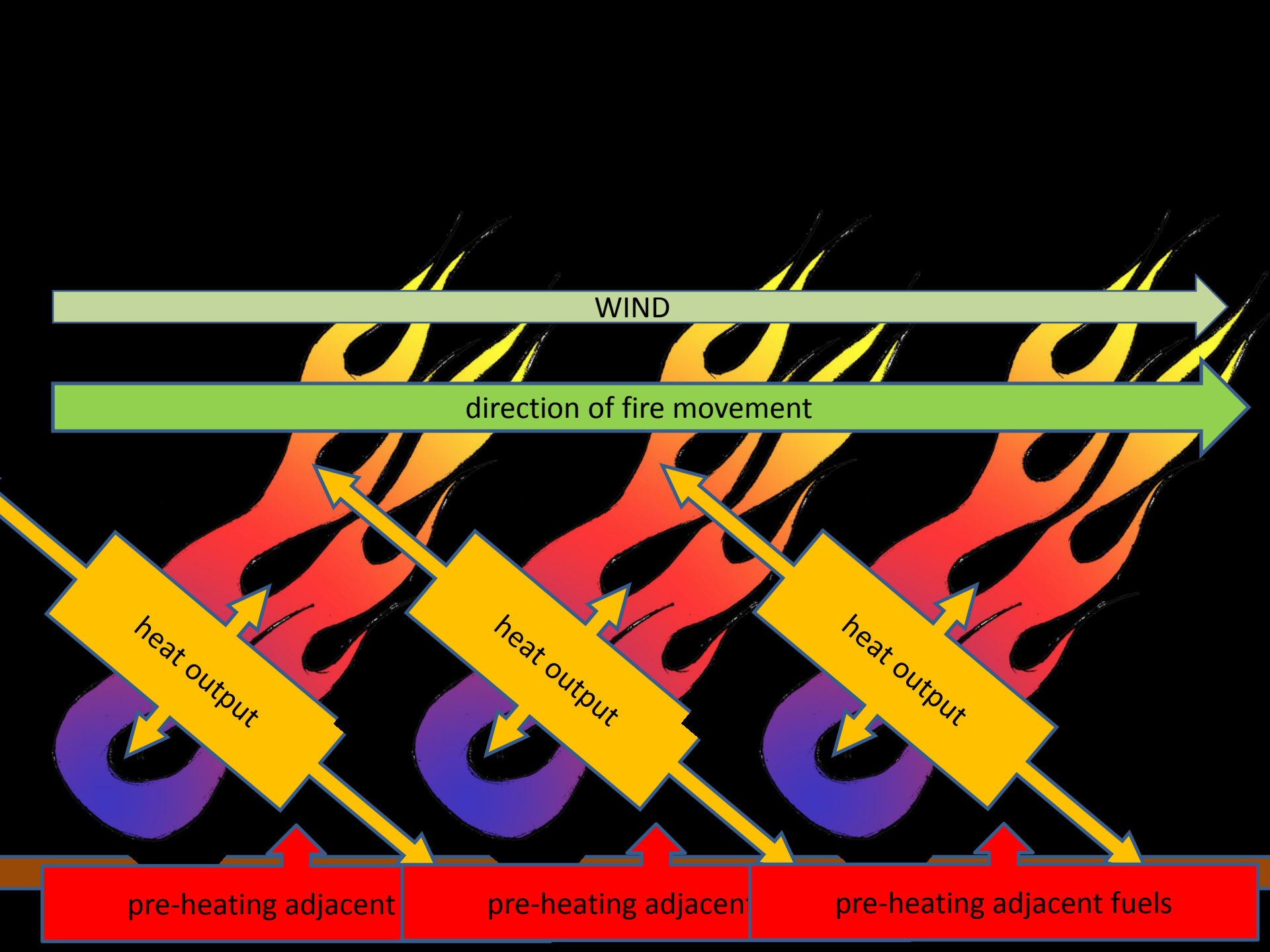
Case 2: Burning fuel on sloping ground

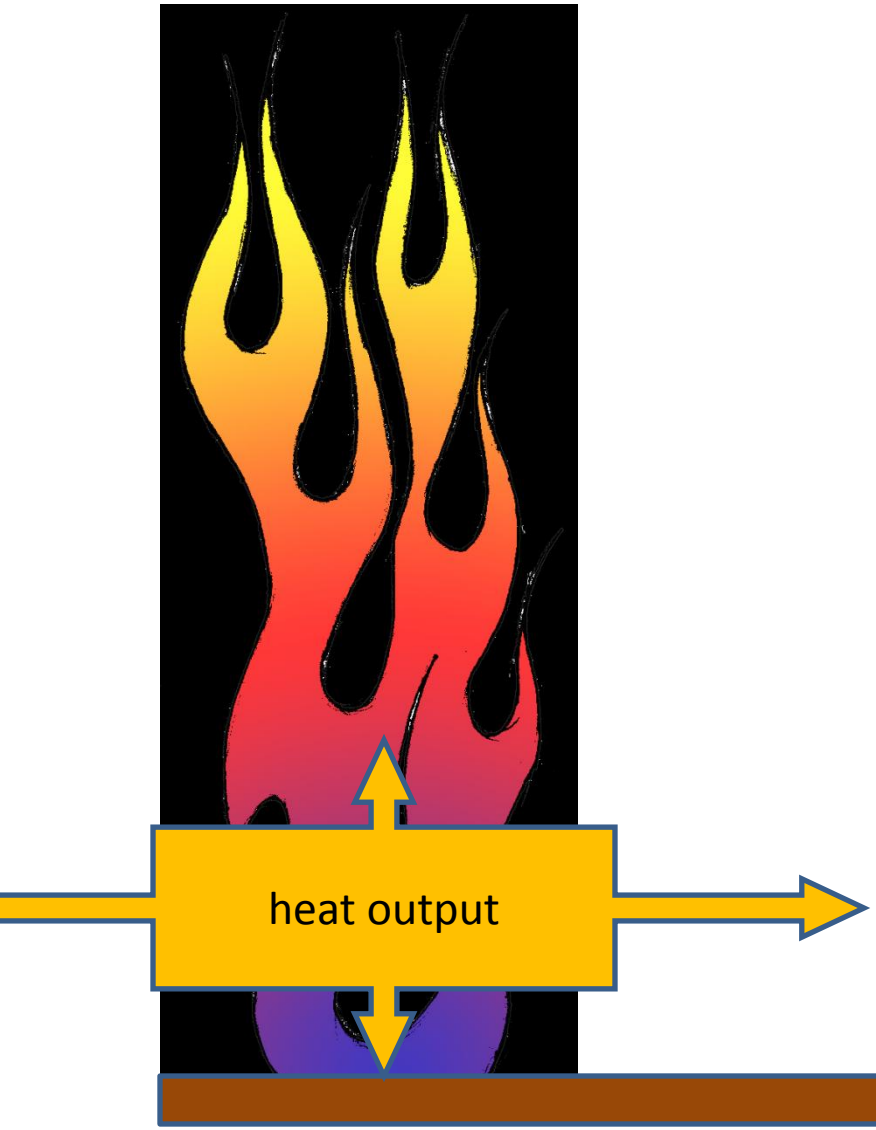



direction of fire movement
pre-heating adjacent fuels
pre-heating adjacent fuels
pre-heating adjacent fuels

Case 3: Flat ground with wind




WIND
direction of fire movement
heat output
heat output
heat output
pre-heating adjacent
pre-heating adjacen
pre-heating adjacent fuels



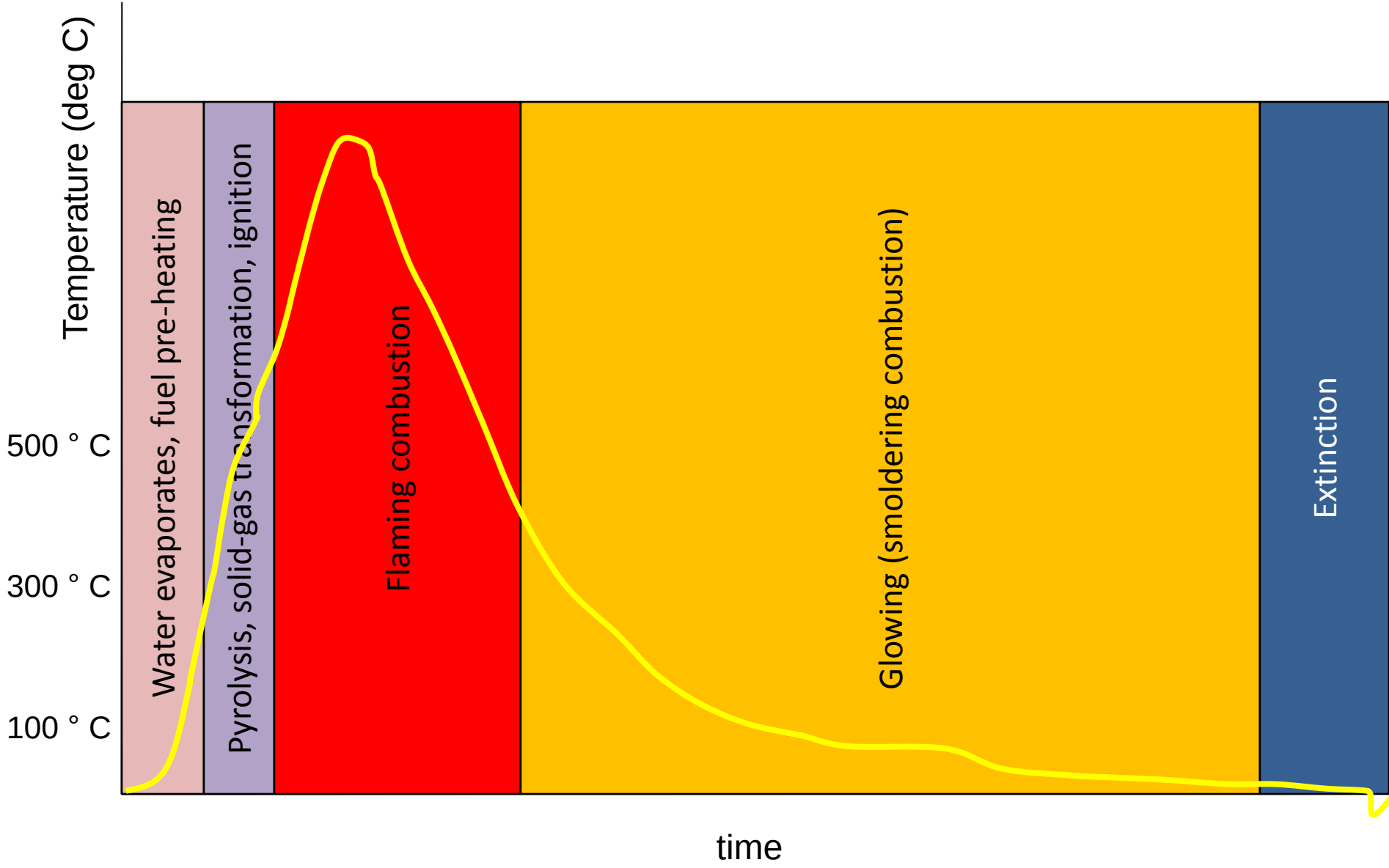
So remember:

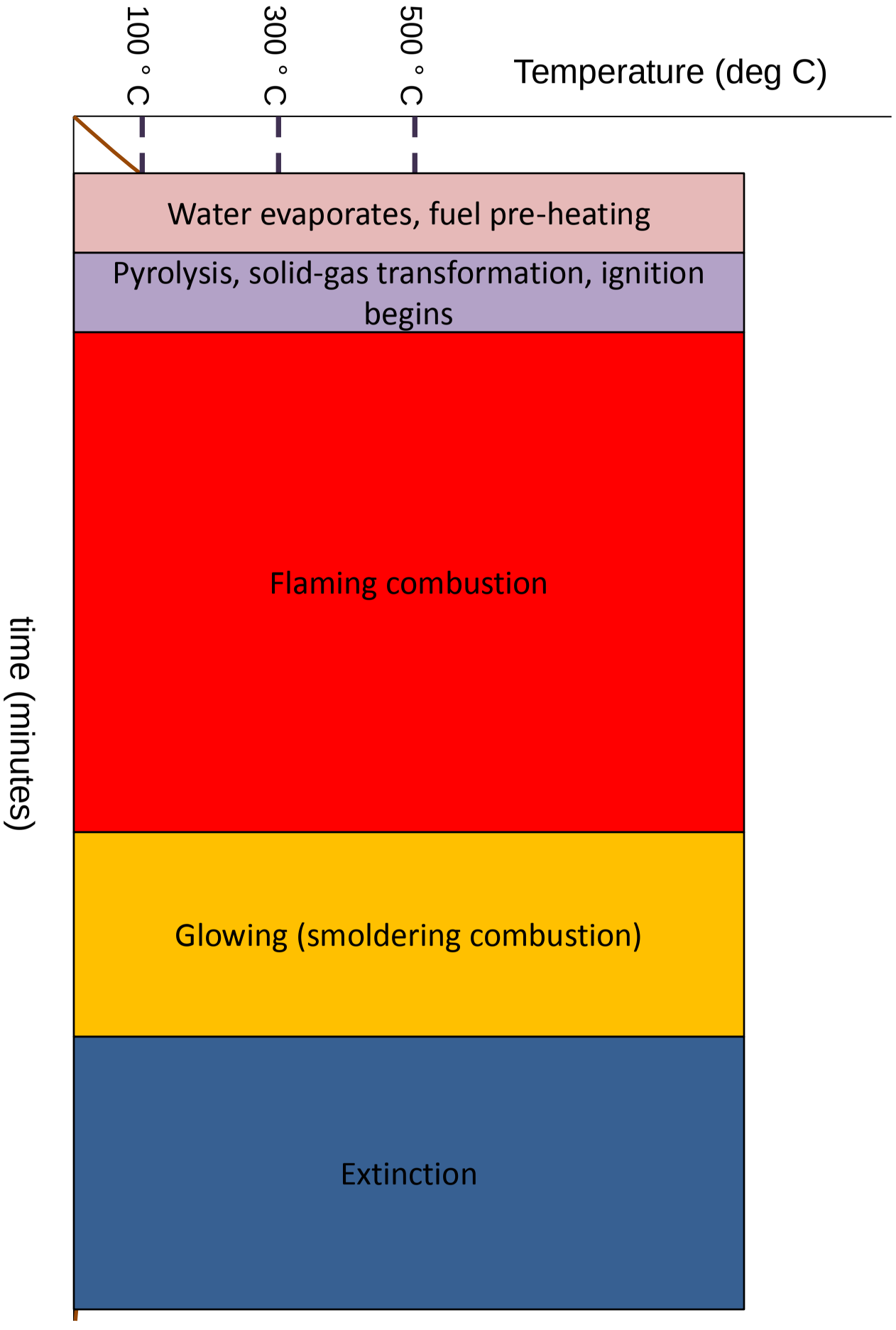
1. Heat output from Phase II combustion is distributed by radiation and convection, which…
2. …pre-heats adjacent fuels, which…
3. …keeps the combustion chain reaction going and…
4. …causes the fire to move in space!

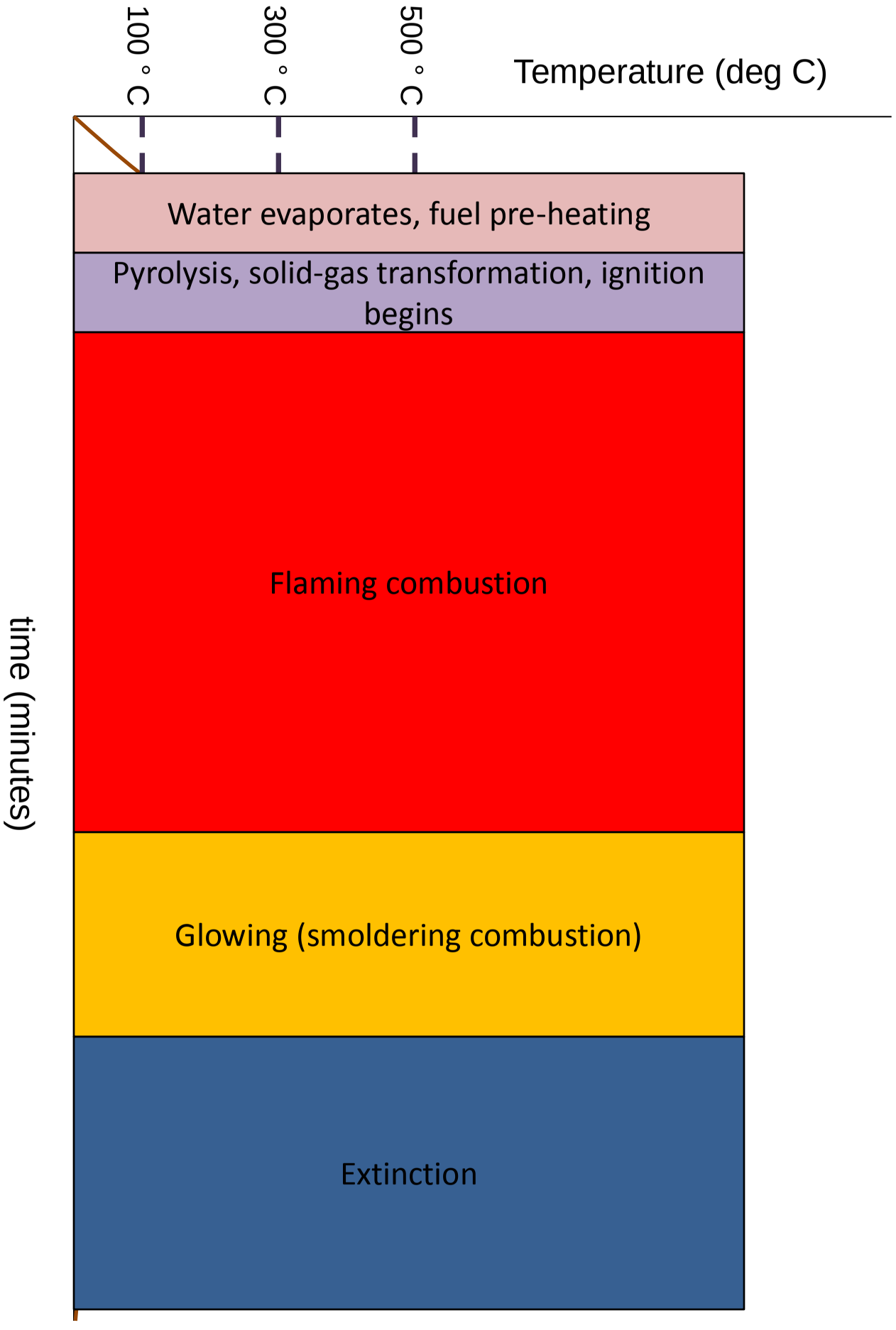
What helps fires spread directionally?:

- TOPOGRAPHY (how?)
  - Fuels uphill are exposed more to radiation heat, so they pre-heat faster and then ignite
- WIND
  - Wind bends flames toward ground on leeward side, preheating those fuels faster

The time progression of a spreading fire




100 ° C
300 ° C
500 ° C
Temperature (deg C)
Water evaporates, fuel pre-heating
Pyrolysis, solid-gas transformation, ignition begins
Flaming combustion
Glowing (smoldering combustion)
Extinction
time (minutes)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How do we measure fire behavior?

What are the main properties we would use to characterize a spreading fire?

- temperature
- heat output (energy)
- direction and speed of movement
- physical dimensions (size)
- duration (how long it lasts)

Property	Manifestation	What is measured	Units (SI)	How measured
Rate of spread	Movement of flaming front	Distance/time	m min^{-1}	Laser, tape, benchmarks
Flaming front	Overall area of leading edge of fire	Distance along front	m	Laser, tape, benchmarks
Residence time	Time extent of combustion at a given point	Time	sec, min, hr	Various chronometers
Flame height	Highest level of flame	Vertical distance from flame tip to ground	m	Laser, tape, benchmarks
Temperature	Physical heat output	Temp at various parts of fire	° C	Thermometer, thermocouple, infrared sensor
Reaction intensity	Energy emitted by combustion processes	Energy output per unit space per unit time	kJ m^{-2} min^{-1}	Heat flux sensor, digital infrared camera
Fireline intensity	Energy output along flaming front	Heat output per unit length of fireline	kw m^{-1}	Heat flux sensor, digital infrared camera

Energy: what is a “joule”?

- BTU (Olde English units): amount of energy required to raise one pound of water 1 °F
- SI units!
- Joule: a measure of energy or work
- The amount of work done by a force of one newton moving an object a distance of one meter
  - ≈ the amount of kinetic energy in a textbook dropped to the floor (2 kg mass moving at 1 m sec^{-1})
- 4.2 J = 1 thermochemical calorie

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-131

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Charts for Interpreting Wildland Fire Behavior Characteristics

**Patricia L. Andrews
and Richard C. Rothermel**

FIRE CHARACTERISTICS CHARTS

A fire characteristics chart is a graph that illustrates the two primary characteristics of fire behavior—spread rate and intensity. Overall fire severity, as well as the character of the fire, can be inferred from the location of a point representing the fire on the chart. The chart is mainly useful as a communication aid. The fire characteristics chart can be used for site-specific predictions of fire behavior (fig. 1) or for National Fire-Danger Rating System (NFDRS) indexes and components (fig. 2).

There is a pressing need for analysis of fire behavior and a clear understanding of the analysis at all levels of management. Fire policy on National Forests has shifted emphasis from fire control to fire management. In addition to traditional fire control and use activities, a successful fire manager must also evaluate alternative fire management strategies in relation to land and resource management objectives. A vital part of this process is communication with other resource specialists who may not be familiar with the National Fire-Danger Rating System or methods for predicting site-specific fire behavior. Quantitative descriptors of fire behavior are becoming more widely used due to the prevalence of automated systems (Rothermel 1980). The hand-held TI-59 calculator with a Fire Danger/Fire Behavior Custom Read Only Memory (CROM) is an example of technology that is reaching every level of fire manager—from dispatchers to regional planners (Burgan 1980). Fire characteristics charts allow graphic presentation of quantitative fire behavior information in a form that is readily understood.

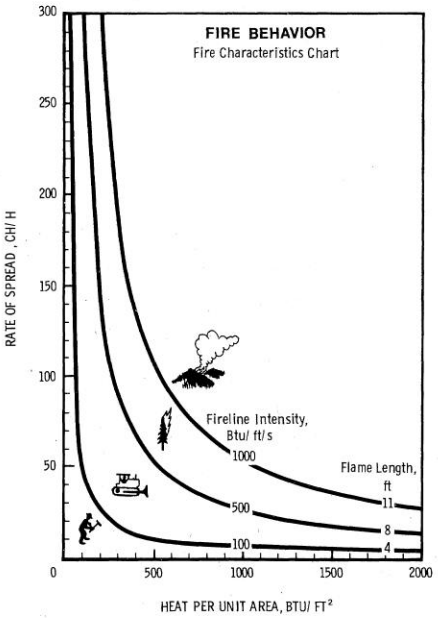


Figure 1.—Fire behavior fire characteristics chart.

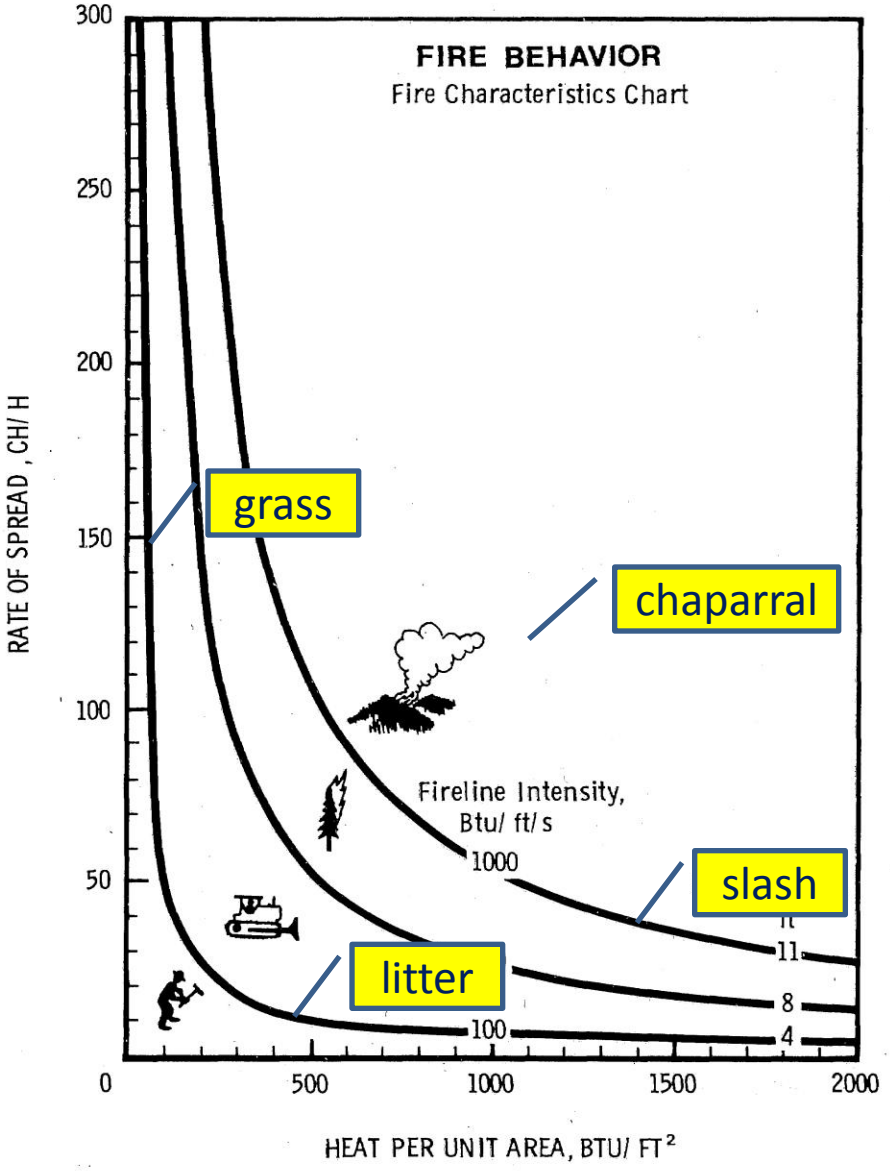


Figure 1.—Fire behavior fire characteristics chart.

How do these properties relate?

- Example: heat per unit area, rate of spread, and flame length
- 1 chain = 66 ft (80 chains/mile)…
- Fireline intensity and flame length increase with heat energy and rate of spread
- This determines how (if at all) a fire can be controlled

Rate of spread: The details*

Rate of spread (m min^{-1}) =

$$\frac{(\text{reaction intensity}) \times (\text{energy flux}) \times (1 + \text{slope coefficient} + \text{wind coefficient})}{(\text{fuelbed bulk density}) \times (\text{heat of pre-ignition}) \times (1\text{-proportion of fuel pre-heated})}$$

* Don't try to memorize this – instead, think about the terms!
What is in the numerator, and what in the denominator?

Rate of spread: The essence

Rate of spread $\propto$ (is proportional to):

$$\frac{\text{heat source}}{\text{heat sink}}$$

Types of fire and the Fire Behavior Triangle

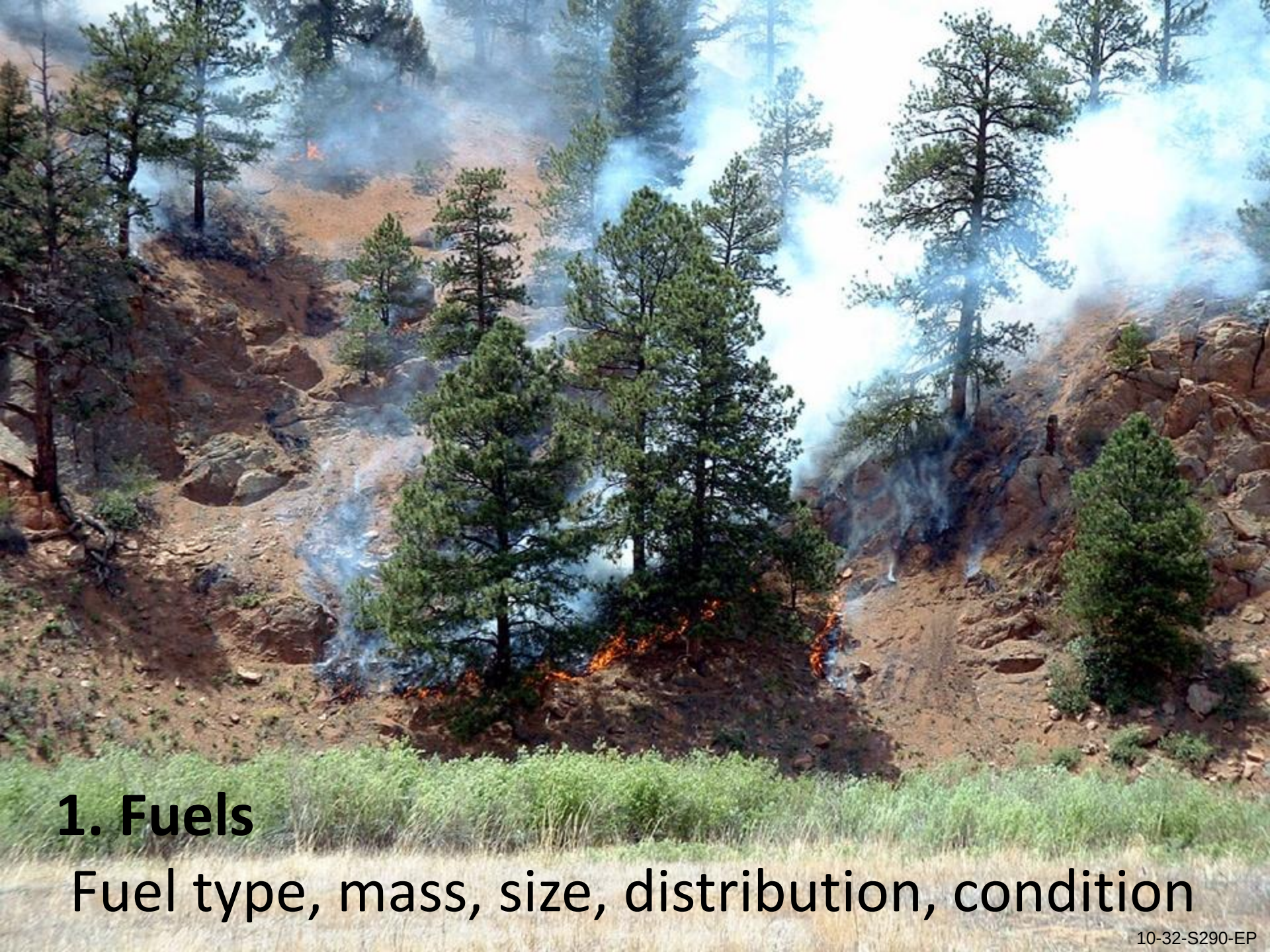

o understand what determines:
urns, when, where
tput
spread
al effects
Photo - John McColgan BLM Alaska Fire Service

Terminology: types of fire

- **Ground Fire**
  - Subsurface in organic material
    - e.g. peat bog fire, forest floor duff
- **Surface Fire**
  - Fire on top of soil surface
    - e.g. grass litter, small branches in forest fire; cured grasses in grassland
- **Crown Fire**
  - Burning in crowns of trees, chaparral

The second “fire triangle”: fire behavior

- **What factors govern fire behavior?**
- Larger scale than combustion
  - 1 m^2 – 10 km^2
- Longer time scales
  - Minutes to days, even weeks
- How fire spreads through a grassland or stand of forest, to landscape scale
- The three legs of the fire behavior triangle:

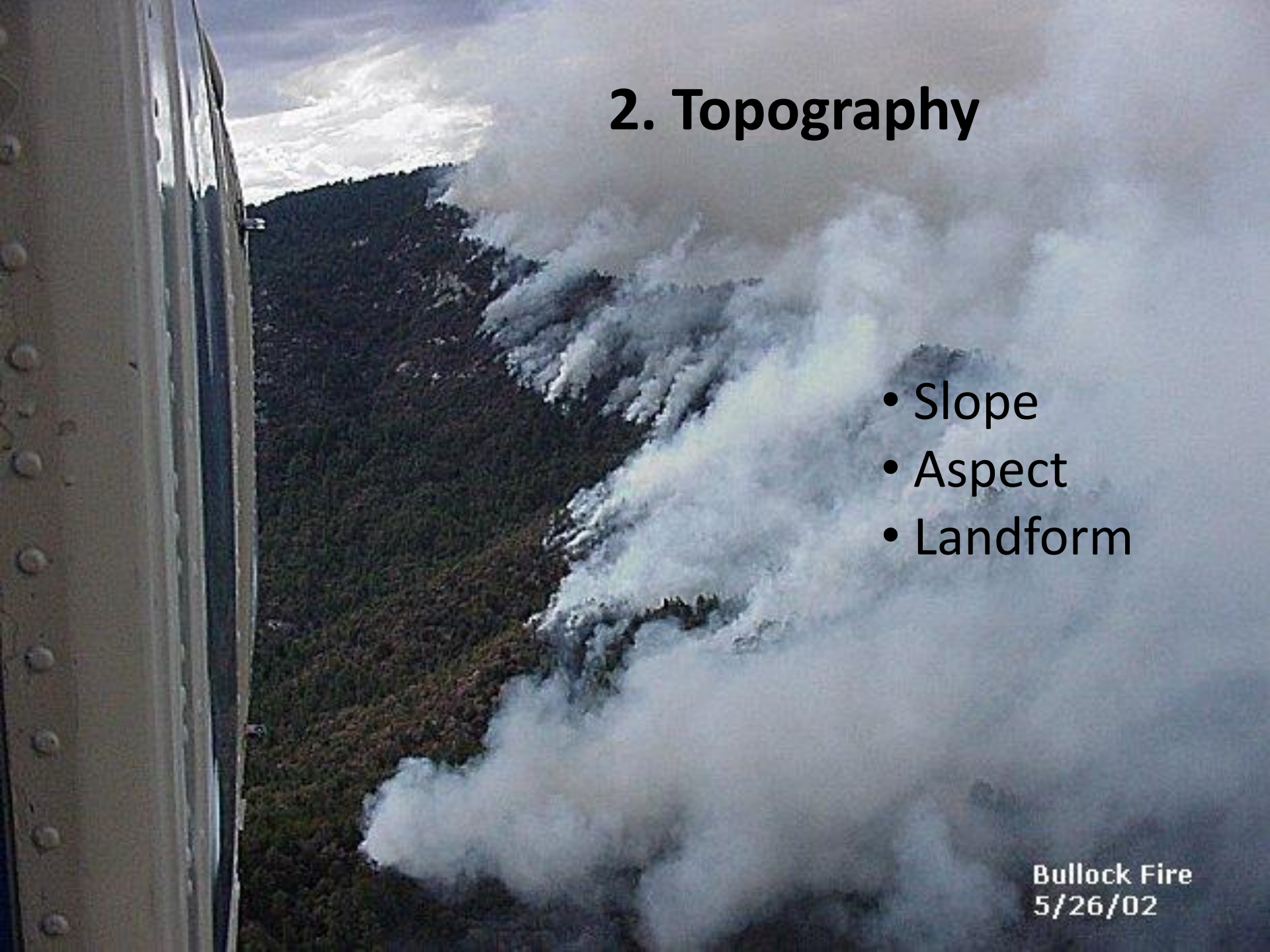


1. Fuels

Fuel type, mass, size, distribution, condition

2. Weather

- Temperature
- Humidity
- Wind speed and direction
- Precipitation
- Lightning



2. Topography

- Slope
- Aspect
- Landform

The Fire Behavior Triangle

- Wind, Atmospheric Stability, Temperature, Humidity

- Terrain
- Aspect
- Elevation

- Fuel Moisture
- Fuel Temperature
- Fuel Characteristics


Next: Understanding fuels