LAFARGE
Building better cities™

BioCleanTech in the Thermal Industrial Context
August 24, 2016

About Lafarge Canada Inc
- A Member of LafargeHolcim

- Lafarge Canada Inc. consists of two separate business units: Western Canada and Eastern Canada. Separated by the Manitoba border

- We provide building materials solutions for the construction sector using cement, ready mix concrete, asphalt,concrete products, and aggregates.

- Lafarge is not just a material supplier
  - buildings and bridges,
  - brownfield soil remediation,
  - energy,
  - mining and
  - pavement infrastructures.

- R&D network of more than 1,000 experts, the world's largest building materials research centre in Lyon, France.

Why is Lafarge here at BioCleanTech?

Four Reasons

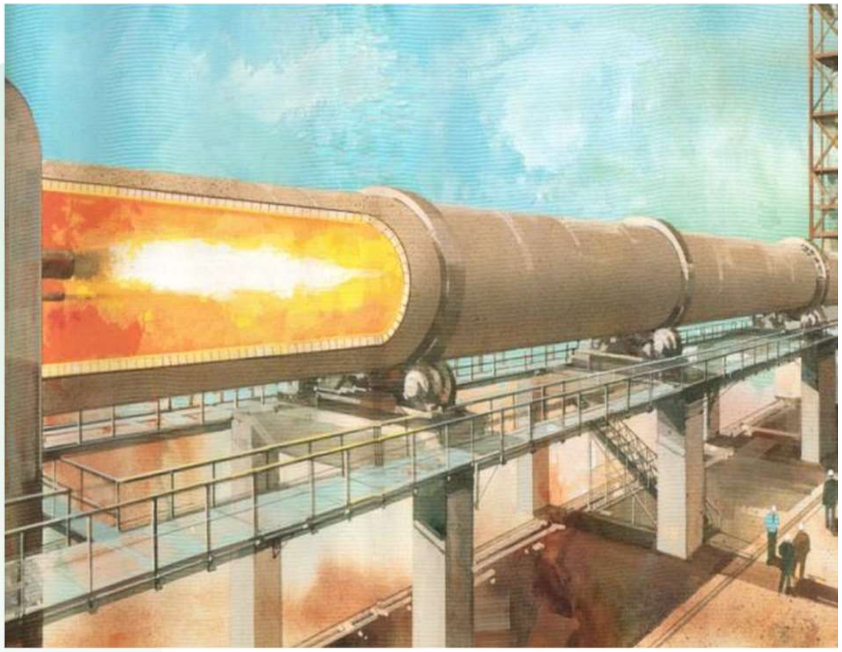
Cement, steel, and greenhouse companies

- **Lafarge sees challenges and opportunities in climate change**
  - Our final products are low in carbon intensity
  - We see a transformative change in building design coming (eg “Net Zero”)
  - We have the world’s largest building materials research lab (Lyon, France)
  - Because there is more concrete sold than all other building materials combined…
    - We are the second largest carbon emitter company in the world
    - Cement is 5% of the world’s CO2 emissions
    - Canada is 2%
  - Solutions here can apply around the world
- **We need thermal energy and lots of it**
  - Replace fossil fuels with biogenic fuels
- **Carbon capture into Algae is already underway**
  - Pond Biofuels demonstration plant in St. Mary’s Cement plant in Ontario
- **Partnerships are essential**
  - Industry – industry
  - Industry – Academic
  - Industry – Governments
  - Governments should partner not just merely regulate

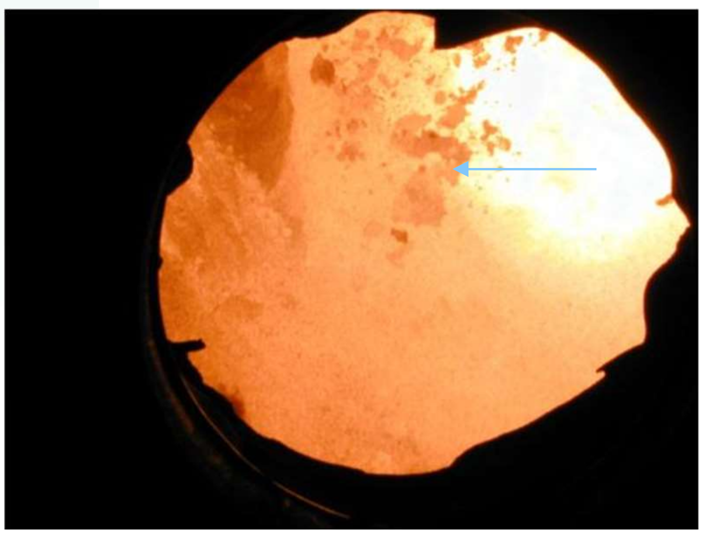
Existing Partnerships across Lafarge Canada

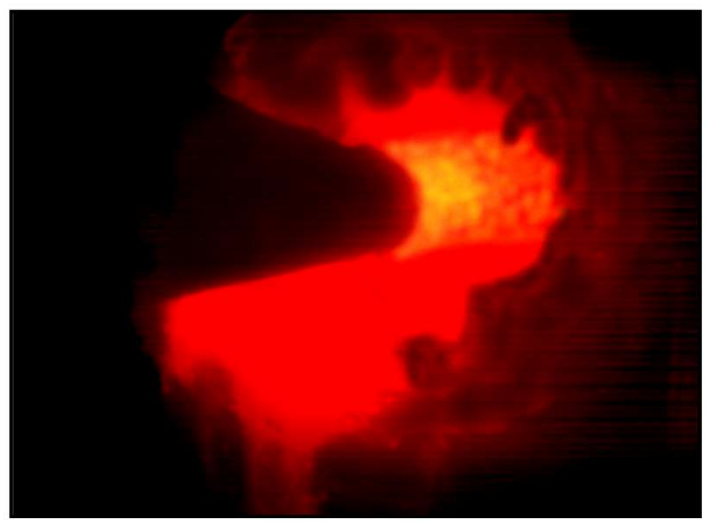
- **British Columbia**
  - Carbon Tax funds being re-invested in low(er) carbon fuel infrastructure
- **Alberta**
  - University of Calgary, Pembina
  - More news to come
  - Seeking government agency partnerships
- **Ontario**
  - Queen's University, WWF Canada (earlier), Cement Association
  - Funding from NRCan EcoEnergy, OCE, and CMC ("Cement 2020" project)
  - World class research (emission testing, LCAs, flame modellng, drying technology)
  - Research led in part to O.Reg 79/15
  - Virgin biomass is fully approved, waiting for economics to work ("Energy Farm" project)
- **Quebec**
  - Cap & Trade funds are re-invested
  - Seeking government agency partnerships
- **Nova Scotia**
  - University of Dalhousie
  - More news to come

Cement Kiln Operation



The rotary kiln is on an slight incline and raw materials are added at the high end and work their way down the kiln. Fuel is injected at the downhill end. Average temperature of 1450 C is reached. Flame and product are in the same vicinity. Fuels can be injected in main burner, mid-kiln, or in Pre-Heater sections.





What types of waste are used today?

Current Fuel Use

Across Canadian Cement Plants

- **British Columbia**
  - Treated wood chips, K-Cups, non-recyclable rubber, non-recyclable plastics, C&D, railway ties, wood fines, tire fluff, carpet
- **Alberta**
  - Studies underway
- **Ontario**
  - Lafarge (Bath) – (Phase 1) woodwaste, virgin biomasss (complete); railway ties, C&D, asphalt shingles (Phase 2); non-recyclable packaging, manufacturing composites, K-Cups, carpets/textiles; (Phase 3) non-recyclable plastics & rubber (incl. tire fluff)
  - CRH (Clarkson) – Used oil, solvents
  - Essroc (Picton) – No current use
  - St. Mary’s (Bowmanville) – Woodwaste (approved), plastics (planned)
  - St. Mary’s (St. Mary’s) – No current use
  - Federal White – No current Use
- **Quebec**
  - Used tires, C&D, shingles, etc
- **Nova Scotia**
  - Asphalt shingles, non-recyclable plastics, scrap tires (pilot stage)



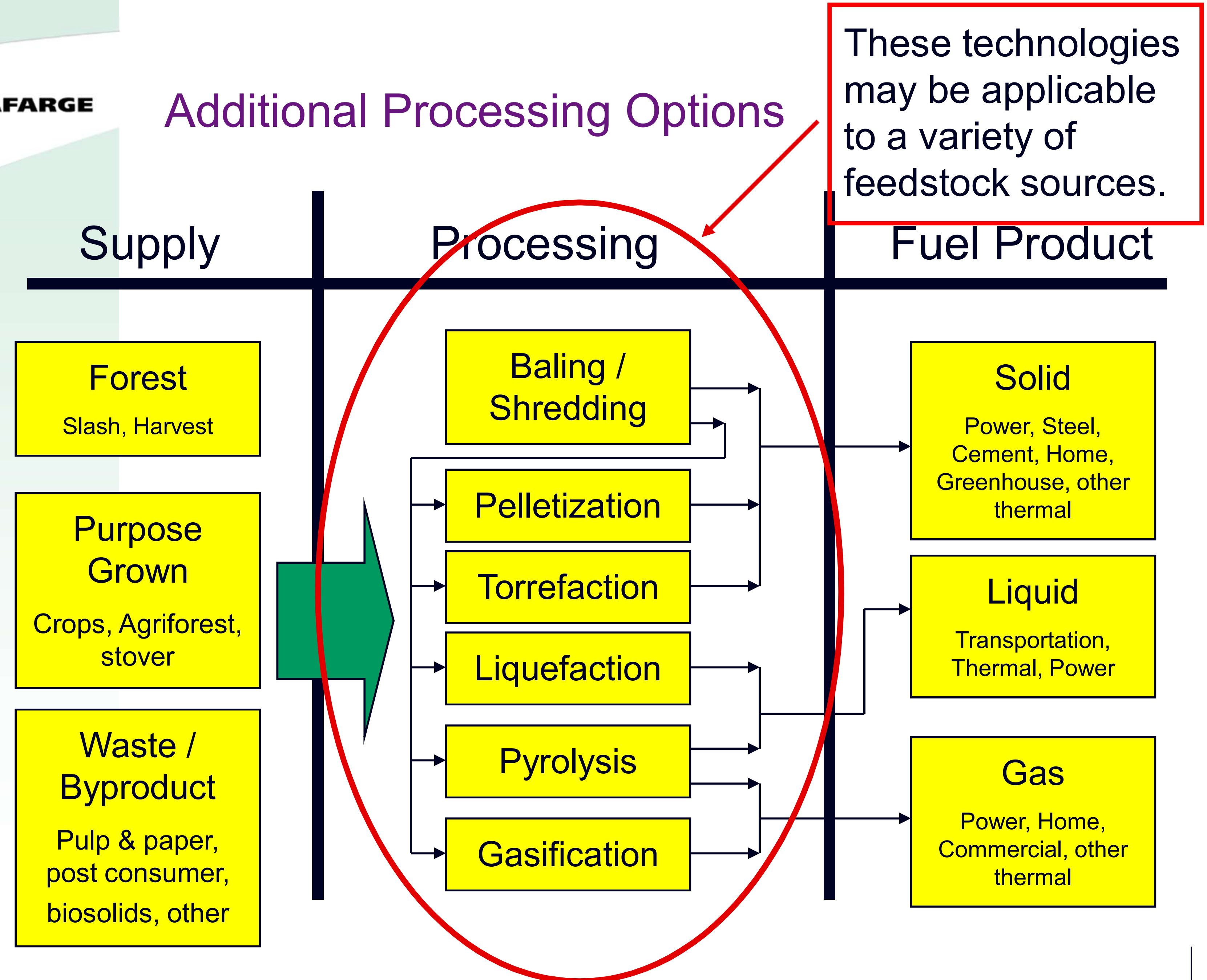
Comparing Two Fuels

Parameter	Coal	Railway Ties	Percent
Gross tne CO_2 per tne of fuel	2.42	0.83	34.3%
% Biomass	0%	75%	-
Net tne CO_2 per tne of fuel	2.42	0.21	8.7%
LHV GJ/tne	24.9	10.8	43.4%
Net tne CO_2 per GJ	0.097	0.019	19.6%
Cost @ $10/tne CO_2 / Tne	$24.2	$2.1	8.7%
Cost @ $10/tne CO_2 / GJ	$0.97	$0.19	19.6%

Observations

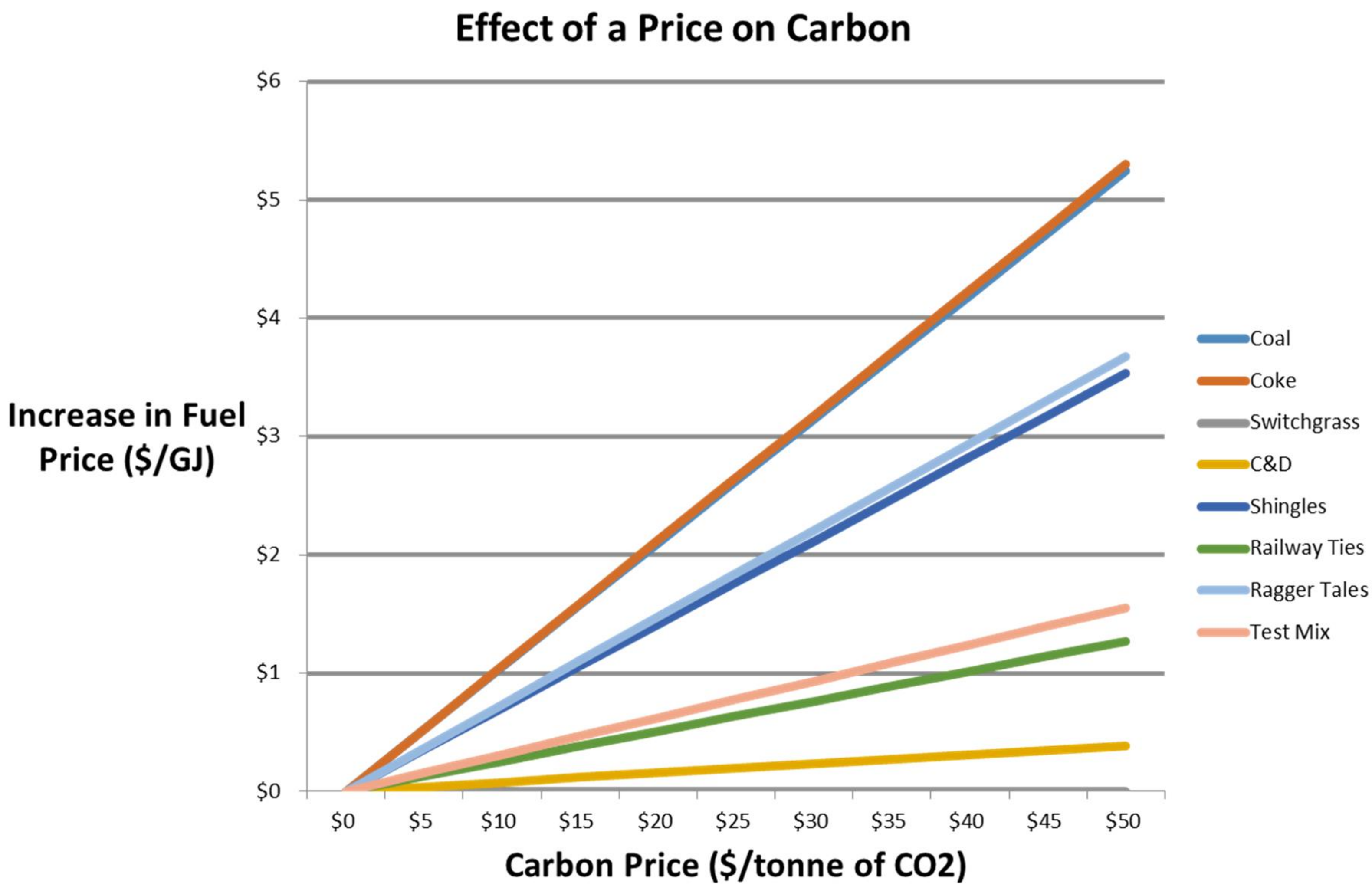
1. It takes 2.5 tonnes of railway ties to replace a tonne of coal on an energy basis
2. Factoring in bulk density means it can take 3-5 truckload of ties to replace a truck load of coal
3. Does not include transportation costs nor associated carbon costs (i.e. at 20 tnes/truck, it will take 3000-5000 trucks of railway ties to replace a 20,000 tonne boat shipment of coal)

Additional Processing Options



So what does all of this mean to the cost of fuel purchases with a Price on Carbon added in?

Putting it all together



Carbon Capture

- **Cement kilns have high concentrations of CO_2**
  - 70% from converting liimestone to lime, 30% from fuel
  - 17-19% CO_2 in stack gas is typical
  - Large supply in one place
- **Algae**
  - Multi-year demonstration project at St. Mary's Cement in Ontario (promising)
  - Algae could be a recycled fuel
  - Use as a bioproduct feedstock or fertilizer may be more promising
- **Carbon Capture**
  - Technologies (new and emerging) exist
  - What do we do with the CO_2?
- **Product Development**
  - Contempra and Carbon Cure
    - Both reduce clinker content and so lowers carbon intensity of Concrete
  - Solidia uses CO_2 instead of water to create a new form of concrete
  - Aether is an entirely new way to make cement
- **Our customer's customer – the biggest opportunity!**

Contact Information

Rob Cumming, MASc, P.Eng

Director, Environment, Lafarge Canada

Robert.Cumming@lafargeholcim.com

(905) 738-7741

The Language of Fuels

The language of fuels

- **Typically waste management companies talk about**
  - Truck loads
  - Tonnes or m3
  - “T&D”
  - $/tonne
  - $/load
- **Fuel purchasing companies talk about**
  - Gigajoules or BTUs
  - Fuel cost FOB the plant
  - $/GJ
- **We’ll now talk about how to convert $/tonne to $/GJ**
  - Difference between Higher Heating Value and Lower Heating Value
  - Influence of moisture
  - Influence of chemistry
  - Influence of biogenic carbon

Note: “tonne” is used in common practice to represent 1000 kg of fuel. Under official SI (metric) rules, we should use Mg but we’ll use the common parlance here. Don’t confuse with ton which is 2000 lb.

Combustion Chemistry

- **Combustion is a chemical reaction that oxidizes carbon based fuels into water and carbon dioxide.**
- **Some fuels produce less CO_2 per Gigajoule of heat release**

$$C_xH_yO_z + (x + 0.25y - z/2)O_2 \Rightarrow xCO_2 + (y/2)H_2O + heat$$

Ultimate analysis gives you x, y, and z (after you convert to kgmols from weight)

This can be calculated and lead to kg of CO_2 produced

You need this to correct from "High Heat Value" to "Low Heat Value"

Proximate analysis gives you this (but correct to lower heating value on an "as received basis")

Heating Value

A SIMPLIFIED description of the laboratory method

- **A bomb calorimeter is used**
- **1 Calorie is nominally the amount of heat to raise the temperature of one Litre of water at atmospheric pressure by 1 degree Celsius**
  - 1 calorie = 4.184 Joules
- **Conceptually, you "burn" a known mass of sample inside a "bomb" inside a known volume of water and then you measure the increase in water temperature and work backwards to calculate the amount of Joules released and divide this by the mass of the sample**
- **KEY POINT is that the water temperature stays below the boiling point and the "Bomb" will also stay at the same temperature as the water.**
  - Any water vapour produced will condense inside the "bomb"
  - This releases more energy (ie it take energy to evaporate water) in condensation
  - This is why this lab test produces the Gross Higher Heating Value
  - In many combustion scenarios, the water vapour leaves the stack and the fuel user doesn't benefit from this energy

Calculating Fuel Quality (Part 1)

Calculating carbon emitted

- **“Ultimate” analysis includes a percent carbon by weight**
- **Example 1: Coal**
  - 65.9 % Carbon (by weight as received, i.e. wet)
  - 2.85% Hydrogen (by weight, as received, i.e. wet)
  - 5.0% Moisture (by weight, as received)
  - The remaining composition is ash, oxygen, nitrogen, etc

“Tne” = Tonne

- **1 tonne of coal will emit 659 kg of carbon (C)**
  - 659 kg of carbon divided by 12.011 kg/kgmol* equates to 54.86 kgmols of carbon
  - “x” kgmol of carbon will produce “x” kgmol of CO2 (or in this case 54.56 kgmol)
  - 54.86 kgmol of CO2 multiplied by 44.01 kg/kgmol* equates to 2,424 kg of CO2
  - **Shortcut multiply 659 kg by 3.63 to get kg of CO2**
- **1 tonne of coal combusts to form 2.41 tonnes of CO2**
- **A price on carbon of $10/tne of CO2**
  - Equates to $24.2/tne increase in price of coal

* Molecular weight of C and CO2 respectively

Fuel Quality (Part 2)

Correcting HHV to LHV

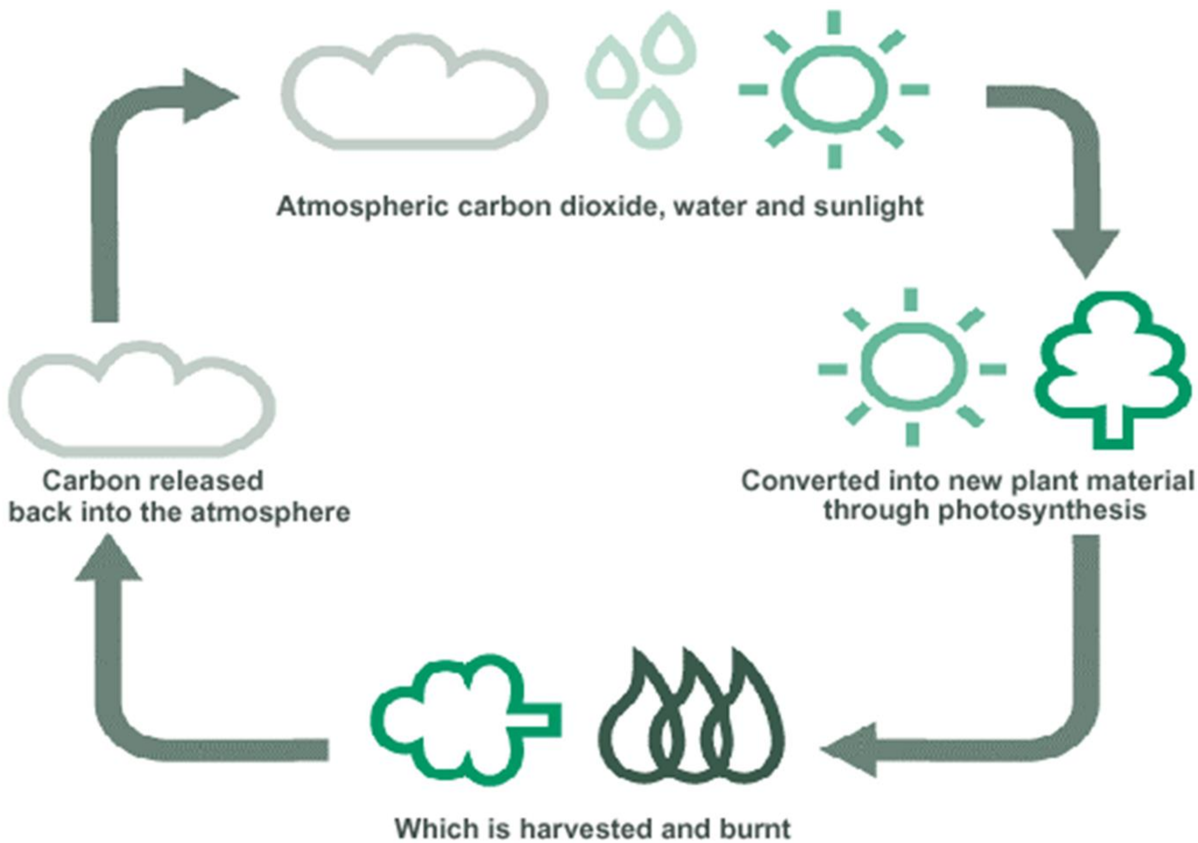
- **Proximate analysis produces Gross Heating Value (HHV)**
- **Example 1: Coal**
  - 11,000 BTU/lb (as received, i.e. wet)
  - 2.85% Hydrogen (by weight, as received, i.e. wet)
  - 5.0% Moisture (by weight, as received)
- **Convert BTU/lb to GJ/tne**
  - Multiply 11,000 by 0.00233 to get 25.6 GJ/tne (unit of measure conversion)
- **Energy lost evaporating combustion generated water**
  - Remember this? $C_xH_yO_z + (x + 0.25y - z/2)O_2 \Rightarrow xCO_2 + (y/2)H_2O + \text{heat}$
  - The hydrogen in the fuel will form water
  - 28.5 kg of hydrogen in this example, equates to 28.3 kgmol of Hydrogen ("y")
  - This produces "y/2" kgmol of H2O or 28.3 ÷ 2 = 14.14 kgmol of H2O
  - 14.14 kgmol of H2O equates to 255 kg of water (multiply by molecular weight)
- **Free moisture of 5% or 50 kg of water**
- **Total of 305 kg water formed from combustion of 1 tonne of this fuel**

Fuel Quality (Part 2) Continued

Correcting HHV to LHV

- **Latent heat of vaporization**
  - Essentially the amount of heat (measured inGJ) to boil water
  - Some simplifications will apply from this point
    - We'll ignore the heat needed to warm up the fuel mass to stack temperature for example
  - It takes 2,264.876 kJ of heat to evaporate water at 100 Celsius (we'll use this)
  - Recall that 1 tonne of this coal produces 305 kg of water
  - This equates to 0.69 GJ lost to water vapour for the tonne of fuel consumed
  - Subtract 0.69 GJ/tne from 25.6 GJ/tne to get LHV of 24.9 GJ/tne
- **Example 2: Railway ties**
  - 22.67% Carbon, 2.45% Hydrogen, 23.93% Moisture, LHV 5100 BTU/lb
  - All "as received" on a wt basis
  - Results
    - 830 kg CO_2/tne
    - 458.2 kg water/tne
    - 10.82 GJ/tne LHV

One more thing: the Biogenic Factor



Biomass Carbon Cycle

Experimental Biogenic Carbon Results

Results are +/- 3%

Fuel Description	Percent Biogenic Content
Petroleum Coke	0
Coal	0.6
Shredded Railway Tie	73 76 74
Shredded Asphalt Shingle	21
	19
	19

- **Observations**
  1. Biomass refers to natural sources of carbon such as wood, grasses, seeds, oat hulls, coffee grounds, biosolids, food waste, energy crops, soil, etc. These are all 100% biogenic carbon containing materials.
  2. Virgin biomass is biomass from non-waste sources (includes woodwaste)
  3. Biogenic testing uses carbon dating techniques

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Fuel Calculation Worksheet Tool (available on request)

Fuel Calculation Template

Input Data (manually enter data into yellow cells)

Fuel Name	Coal	
Proximate Analysis		
Percent Carbon	66%	Mass basis, as received
Percent Hydrogen	3%	Mass basis, as received
Higher Heating Value	25.63	GJ/Tonne, as received, Gross or HHV
Moisture Content	5%	Percent
Biogenic content	0%	Percent

Output Data [Based on 1 metric tonne (tne) which is 1000 kg]

Tonnes of CO2 produced per tonne of fuel	2.41	Tonnes
Tonnes of H20 produced per tonne of fuel	0.30	Tonnes
Lower Heating Value	24.94	GJ/tne (as received)

Effect of a Price on Carbon

	Added Cost of Fuel	
Price per tne of CO2	$/tne	$/GJ
$0	$0	$0.00
$5	$12	$0.48
$10	$24	$0.97
$15	$36	$1.45
$20	$48	$1.94
$25	$60	$2.42
$30	$72	$2.90
$35	$85	$3.39
$40	$97	$3.87
$45	$109	$4.36
$50	$121	$4.84
$55	$133	$5.33
$60	$145	$5.81