9.0 APPENDIX A – USER GUIDE FOR POC WORKBOOK

9.1 INTRODUCTION & GENERAL GUIDANCE

The POC workbook is designed so that a user can estimate the fuel consumption and GHGs that would be generated from a field operation to remediate a SCVF or GM leak of sweet gas and compare that GHG estimate to the GHGs that would occur if the well continued to leak methane.

When a well is abandoned has a gas leak and is left with a vented cap below ground level, it is known that methanotrophic bacterial may consume some of the methane. If the leak rate exceeds a certain level, there is observable vegetation distress above the leak. The adverse effect on vegetation is due to a lack of oxygen in the soil as the bacteria requires oxygen while it consumes methane and also due to displacement of oxygen in the soil from methane and carbon dioxide.

A user can deploy the field practice outlined in the POC workbook to control some of the consumption of methane in the ground and to minimize the risk of vegetation distress resulting from a subsurface sweet gas leak.

When the workbook is opened, the macros must be activated. The sheets in the workbook in which a user may enter well and remediation specific data are as follows:

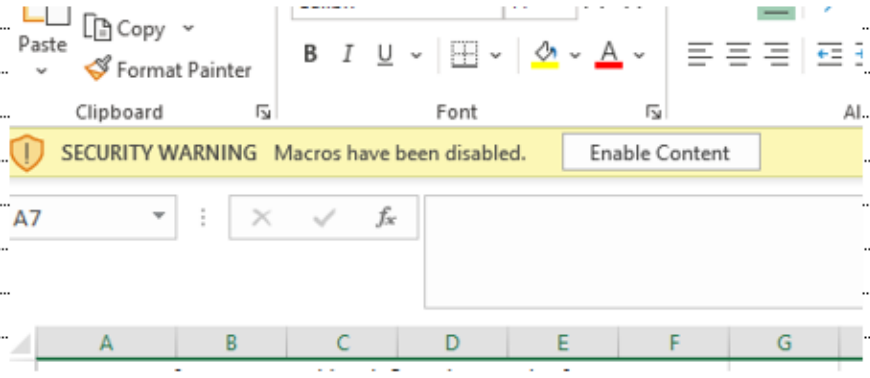
9.1.1 Instructions

This sheet in the POC workbook contains similar information as in this Appendix and this sheet is shown below.

Instructions for Using POC Workbook & Entering Data

Getting Started - Overview (ensure that you have Excel version 2013 or newer)

1 **Enable macros in Excel - click the "Enable Content" button above the formula window:**



2 **Cover Page**

Step 1 - Fill in the company / licensee / permit holder name

Step 2 - Fill in well unique well identifer (UWI)

Step 3 - From the drop down menu, choose the type of well repair operation - inactive or abandoned well

Step 4 - Click the blue button to go to the appropriate "Fuel & GHG" data input sheet

3 **Fuel & GHG Input Data Sheets**

Depending upon the type of well operation chosen in step 3 , you will be taken to either the "Inactive Well" or "Drilling Re-entry" Fuel & GHG data input sheet

There is an option button at the top of each sheet to set the number of all units used to 0 (initialize)

Each input data sheet has instructions on how to fill in the various cells

There is an button at the bottom of the sheet to go to the "Site Conditions & Results" sheet

4 **Site Conditions & Results Sheet**

There are four values / selections to fill in on this page, starting with the actual well leak rate in m^3 / day

The second selection is the average number of intervention attempts reuired for a successful well repair.

The third selection is for a conservative or moderate flow rate of methane through soil per m^2 area.

The fourth selection is the number of days per year that bacteria is expected to be active in the soil.

The results of the calulations are then shown on this sheet

5 **Field Practice Drawings**

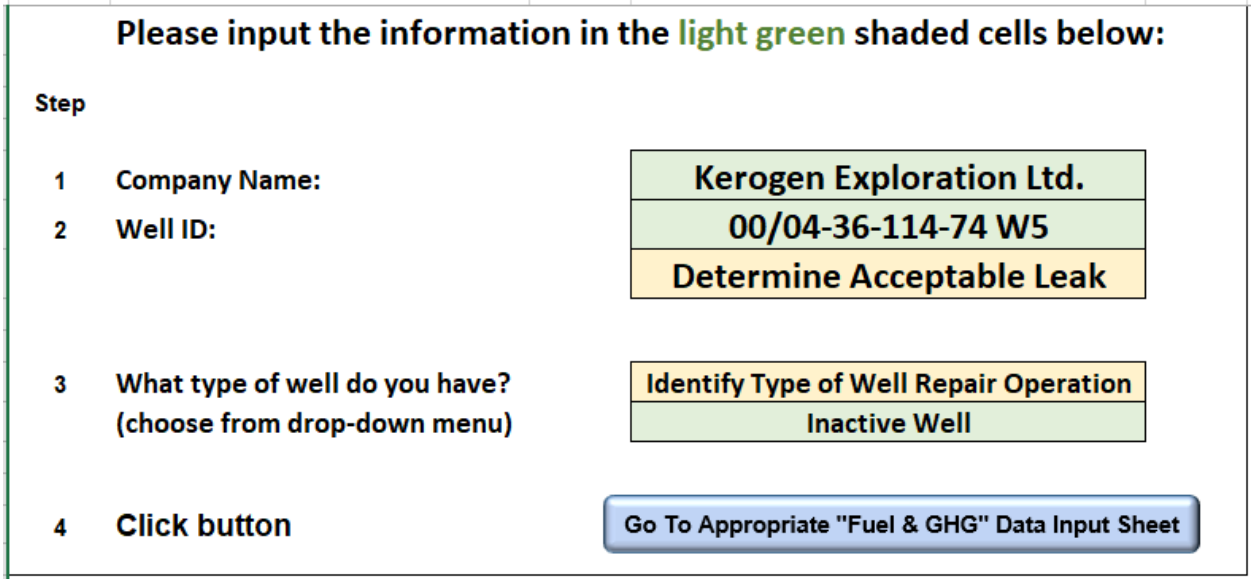
Images of a proposed field practice in which methane can be oxidized in soil are shown on this sheet

Colored sheet tabs	
1	Information is populated by users are on the sheets with green tabs and on green highlighted cells except the "Fuel & GHG" sheets which have multi-colored input cells
2	Sheet tabs that are light yellow provide general information for users and one sheet has drawings for a field recommended practice
3	Sheets with light purple tabs contain data for users who require more technical information
4	Sheets with red tabs contain data tables for calculations, are for administrators editing only and will not be accessible to general users

Details	
1	After enabling macros, enter information in the cover page then click the 'buttons' to go to and enter data on other sheets
2	Input sheets have built in user notes and guidance when the mouse is clicked on some of the data selection cells
3	Determining GHGs from well repairs is calculated in either the sheet called 'Fuel & GHG-Inactive Well' or the one called 'Fuel & GHG-Drilling Re-entry' depending on the selection on the cover sheet
a	In the appropriate GHG Fuel sheet, note the color code guide on top and guidance on cells when the mouse is over the cells where selections can be made, most selections are from drop down menus
b	If the sheet is 'initialized' with the button near the top, the number of equipment pieces will all be reset to zero
c	The input cells on these sheets are designed so that the user has maximum flexibility for the type of operation they are planning
d	Select all equipment that will be needed including mobilization and workers accommodation and ensure that no unnecessary equipment is selected
e	There are several stages of work that may require separate mobilization and the GHG summary is itemised at the bottom of the sheet for each stage
f	For each piece of equipment there are multiple selections, across each row, that must be made in each column for mobilization and for the on site work (be careful not to select unnecessary pieces)
g	The column for 'Field Factor' can be used to make field condition adjustments which may impact fuel consumption and finally the calculated fuel consumption is displayed for each row
h	When an abandoned well is re-entered all of the post repair work to abandon / close the well must be included along with any site reclamation work that was previously done
i	Refer to the sheet called 'General Guide & ROT' to consider some Rules of Thumb related to fuel consumption
j	Ensure that all selections are made for each required equipment piece with no unnecessary equipment selected, an easy cross check can be made by examining the fuel consumption columns
4	On the "Site Conditions and Results" sheet see above point # 4 in "Getting Started"
5	"Field Practice Drawings" has two images in the sheet with guidance in setting up a field site and following a proposed practice to consume methane in soil
6	The sheet called 'Vegetation Roots' contains rooting depth information for most Alberta agricultural species and for some common native grass species which provides guidance for a field practice
7	The sheet called 'Natural Regions' contains information on soils, terrain and vegetation for southern and central Alberta natural regions and sub regions which provides guidance for a field practice

9.1.2 *Cover page*

The company name, well location (UWI) and type of well remediation are entered here and this information is linked to other sheets. The blue button can be clicked on to take the user to the next data input sheet.



9.1.3 *Site conditions and Results*

Final results from all workbook input and calculations are displayed on this sheet. The well leak rate and the average number of well interventions that are required are entered on this sheet. There are also two selections related to consumption of methane in soil. The first option is for a conservative or moderate methane flow though soil. The second choice is the number of days bacteria is expected to be active in soil.

Kerogen Exploration **00/04-36-114-74/03 W5**

Well Leak Rate, Field Conditions and Results

Input Data Required:		
Enter well leak rate (sweet gas / methane)	**1.00**	m^3/ day
Enter average number of intervention attempts required for a successful well leak remediation	**3.0**	For well type, formation & region
Select conservative (0.0241) or moderate (0.0371) oxidation rate of methane in soil	**0.0241**	m^3/d methane flow per m^2 soil surface area
Select number of days/ year ambient temperature is above 7 degrees C and with no frost in ground	**150**	Days per year average

After all data is entered, and if the GHG generated by the well remediation exceeds the GHG from the well leak, before any oxidation of methane in soil, the difference is displayed. If the GHG from well remediation is less than the methane leak GHG, the answer is displayed as 'Not Applicable'. The same logic is applied to the case with partial oxidation of methane in soil.

Final Results:			
Type of well repair selected	Inactive Well		
12 year cumulative GHGs from well leak before full atmospheric oxidation & before any soil oxidation	78.51	Tonnes CO_2 equivalent	
GHGs from fuel consumption of well remediation on either inactive or abandoned well	89.82	Tonnes CO_2 equivalent	
Amount the GHG from well remediation exceeds the cumulative well leak GHG before soil oxidation of methane (negative value = not applicable)	11.31	Tonnes CO_2 equivalent	**Under the input conditions, the atmospheric GHG from well remediation exceeds the atmospheric GHG from the well leak assuming no oxidation of methane in soil**
Methane potentially oxidized in soil when following proposed field practice	0.16	m^3/ day annual average	
12 year cumulative GHG potentially oxidized in soil when following proposed field practice	12.87	Tonnes CO_2 equivalent	
Amount the GHG from well remediation exceeds the cumulative well leak GHG after some soil oxidation of methane (negative value is not applicable)	Not Applicable	Tonnes CO_2 equivalent	

9.1.4 Fuel & GHG-Inactive Well and *Fuel & GHG-Drilling Re-entry*

An inactive well typically has a wellhead that is not cut and capped. An abandoned well is cut and capped below ground level. On the appropriate sheet, the user may select all of the relevant services and operating conditions that are required to remediate the SCVF or GM. Section 8.2 of this report provides more detail on making the appropriate selections.

9.1.5 Field Practice Drawings

This sheet contains images that the user may follow to implement a method of oxidizing some of the methane from a leaking well in soil.

9.1.6 General Guide & ROT

Additional guidance and Rules of Thumb (ROT) are included on this sheet for the user's reference. All the conversion factors used in the POC workbook are summarized in this sheet. The user can also compare the result of their selections regarding fuel consumption for specific pieces of equipment against common rules of thumb.

9.1.7 Vegetation Roots

The rooting depths of the most common Alberta agricultural products are tabulated in this sheet. Some native grass species are also listed with their rooting depths.

9.1.8 Well Leak GHGs

On this sheet the well leak rate, in m3 /day of methane, is used to calculate the cumulative CO2 equivalent in tonnes in the atmosphere.

9.1.9 Methane Consumption in Soil

The leak rate of the well and two other selections are populated into this sheet from the Site Conditions & Results sheet. This sheet also contains data from the Stien and Hettiaratchi[1] study and it will then determine the expected methane consumption by bacteria in the soil when following a recommended field practice. The required radius is calculated for the layer of methanotrophic loam covering the well leak in the proposed field practice.

9.1.10 Subsoil Methane Distribution

This sheet has original drawings of the proposed field practice.

9.1.11 Natural Regions

This sheet provides information on the terrain, soil and vegetation in the Natural Regions and Subregions in Southern and Central Alberta,

9.1.12 Drop down Menus, Factors in Calcs, Diesel Consumption, Natural Gas Consumption & Instructions in Excel

These are hidden and password protected sheets containing data tables with information from public sources. The data is used in various calculations for fuel consumption on different pieces of equipment and services required to conduct well remediation work. These sheets contain information for hidden formulas which cannot be edited without the password.

9.2 FUEL CONSUMPTION AND GHGS FROM WELL REMEDIATION

After someone has written a well remediation program and generated an AFE, they will have most of the basic information needed to use the proof of concept workbook. After entering the company information and the well location in the cover page of the POC workbook, the next step is to select the equipment necessary for conducting the field work.

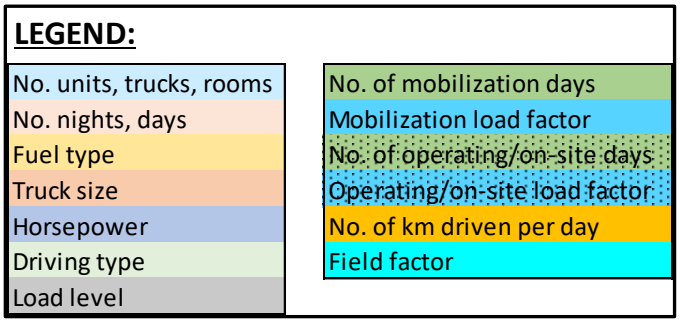
The input sheet for selecting the required equipment on an inactive well with a wellhead is *Fuel & GHG-Inactive Well*. When a well has been abandoned, cut and capped below ground level a small drilling rig is often used for the operation. Drilling operations require some specific support equipment which is listed in *Fuel & GHG-Drilling Re-entry* sheet.

After the required equipment has been identified, the user will make selections for the equipment. The selections either use drop down menus or will accept positive whole integers for input. In most cases there are selections for mobilizing the equipment to the field and for operating conditions while working on site. The POC workbook will then estimate fuel consumption for each piece of equipment during mobilization /demobilization and when the equipment is working onsite.

For each field operation some of the following criterion may be selected by the user but not all selections are required for all types of equipment:

- Man days in a hotel / motel / camp
- Number of units
- Type of fuel used
- Horsepower
- Driving type (city, combined, highway)
- Number of kilometers driven each day
- Field factor adjustment from ideal conditions
- Load level
- Number of mobilization days (days are 24 hours)
- Number of operating days (days are 24 hours)

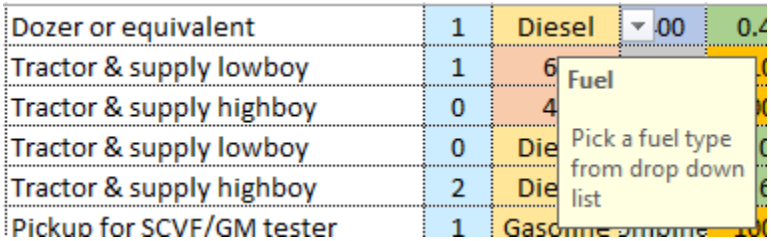
The selections listed above are color coded in the *Fuel & GHG* sheets according to the user requirements and adjustments to fuel consumption calculations.



Below is an image with a sampling of equipment selections and other conditions that the user can chose for the wellsite work. As the selections are made along with the deployment time, the expected fuel consumption for each piece is displayed as reality check.

Major* Activity	Equipment / Items Required	Populate Required Data In Colored Cells Using Dropdown Menus Where Available - Click On Cell For Instructions & See Color Coded Legend								Fuel Consumption			GHG (CO_2)
		Equipment Details			Conditions While Mobilizing		On-Site		Field Factor	Liters / Hour	Nat. Gas SCF/Hr	Liters / 100 km	Released (kg)
	Single service rig - self mobilizing	0	Diesel	400	1.0	50	0.0	30	1.0	0.0	0.0		0.0
	Double service rig - transport to/from locatic	0	60	100	100	1	0.0	30	1.0			0.0	0.0
	Double service rig - self mobilization	0	Diesel	400	1.0	50	0.0	30	1.0	0.0	0.0		0.0
	Double service rig - operating	0	Diesel	400	1.0	50	0.0	30	1.0	0.0	0.0		0.0
	Coil rig - transport to/from location	0	60	100	100	1	0.0	30	1.0			0.0	0.0
	Coil rig - self mobilization	0	Diesel	400	1.0	50	0.0	30	1.0	0.0	0.0		0.0
	Coil rig - operating	0	Diesel	400	1.0	50	0.0	30	1.0	0.0	0.0		0.0

The required data selections and the field factor selections are made by utilizing drop down menus in each cell or by entering positive whole integers. The cells are protected so that an incorrect format cannot be entered, and each cell has a pop-up message to guide the user. In the example below the message is on the fuel selection cell for a Dozer indicating the user needs to click on the arrow symbol to select the correct fuel type (it is currently set to diesel).



As the user makes selections in each row for each piece of equipment, similar guidance is provided. On some types of equipment, such as a tractor and lowboy, the user may have an option to select either a capacity size in tonnes or a horsepower rating for the unit.

For most pieces of equipment, the user can select the mobilization /demobilization time (in 24-hour days) and the expected load factor when mobilizing / demobilizing and the working time on site (in 24-hour days) and the expected load factor while working.

Because there are many variables that affect field operations in Alberta, especially during winter conditions, the user can also make a Field Factor adjustment for the expected fuel consumption. The fuel consumption columns help the user adjust the Field Factor to model actual field experience.

The fuel consumption columns can also be used as check to confirm that no unnecessary equipment weas selected to conduct the field work.

10.0 APPENDIX B – SOURCE OF POC WORKBOOK CONTENTS

The following sources of additional information were used in the POC workbook calculations and conversion factors:

Conversion Factors:
1 Horsepower (HP) = 0.7457 Kilowatts
1 US Gallon (gal) = 3.785412 Liters
1 Standard Cubic Foot (SCF) of Propane = 2,520 British Thermal Units (BTU)
1 SCF of Natural Gas = 1,000 BTU
BTU Ratio of Propane to Natural Gas = 2.52
1 US gal of Liquid Propane = 35.97 SCF of Gaseous Propane
1 Liter of Liquid Propane = 9.50 SCF of Gaseous Propane
1 gram (g) of methane = 22.4 liters (0.0224 m3) at 273 K (0 C) & 1 atm (1.013 bar) i.e. standard conditions (Air Liquide uses 68 kg/m3 at 1.013 bar and 15 C)

CO2 Emissions Data:
From US Environmental Protection Agency (EPA):
1 Liter of diesel burned produces 2.69 kilograms (kg) of Carbon Dioxide (CO2)
1 SCF of natural gas burned produces 0.0549 kg of CO2
1 Liter of propane burned produces 1.62 kg of CO2
1 Liter of gasoline burned produces 2.35 kg of CO2

From the Hotel Carbon Measurement Initiative (HCMI), the accepted standard for the hospitality industry is that 31.1 kg CO2 per room night is produced

Equipment Fuel Consumption Data:
Pickup Trucks (From Natural Resources Canada 2018 Fuel Consumption Guide)

		Liters/100 km			Miles/US Gal		
Fuel	Vehicle Type	City	Highway	Combined	City	Highway	Combined
Gasoline	Ford F-150 4X4 truck (5.0 Liter 8 cyl)	14.6	10.9	13.0	16.1	21.6	18.1
Diesel	Ford F-150 4X4 truck (3.0 Liter, 6 cyl)	11.8	9.3	10.7	19.9	25.3	22.0

A multiplying factor of 1.5 to reflect increased fuel consumption for larger/heavier pickup and crew trucks

Truck Tractor Rolling Stock Using Diesel Fuel:
Based on average values and highway driving from public data on heavy duty truck fuel consumption

	Liters/100 km at Load %			Miles/US Gal at Load %		
Load Level %	*0%*	*50%*	*100%*	*0%*	*50%*	*100%*
42 tonne, 420 HP semi trailer	23.0	29.5	36.5	10.2	8.0	6.4
60 tonne, 420 HP full trailer	31.5	41.5	53.5	7.5	5.7	4.4

Generator Units:
Fuel consumption is based on fuel type (diesel, natural gas, propane), generator size (HP) and load factor (%). Fuel consumption tables were obtained from WorldWide Power Products, LLC and Bryan Power Generation both publicly available sources.

Rules of Thumb:
For Semi-trailer Truck & Trailer units (18 wheelers):
Diesel consumption = 29 - 59 liters of diesel per 100 km (based on 2016 fuel consumption values)
Highway consumption = 6 to 7 miles per US gal
Fast idle consumption is approximately 1 US gal per hour
Driving is approximately 11 US gal per hour

GHG equivalent of methane in the atmosphere to tonnes of CO_2 :
Volume of methane in m^3 x 25 x 0.717 (methane density) is equivalent to tonnes of CO_2

11.0 APPENDIX C – VEGETATION ROOTING DEPTHS

Vegetation Rooting Depths of the Nine Most Common Agricultural Products in Alberta (98% of land use)

Summary of Crop Rooting Depths (m) and Root Distribution in Soil Profile*								
SDA[1] - Effective Rooting Depth (where majority of plant available water is obtaine							Distributio n	m Root Depth
Crop	Range	Low	High	Average	±	AAF[2]	Fan *et al.* (2016) & Canadell *et al.* (1996)	
Alfalfa	1.0–2.0	1	2	1.5	0.5	12	1.356	3.7
Barley	1.0–1.5	1	1.5	1.25	0.3	10	0.996	1.7
Canola	1.0–1.5	1	1.5	1.25	0.3	10	0.902	1.6
Durum Wheat	-	-	-	-	-	-	-	2.2
Hay/Fodder	0.6–1.0	0.6	1	0.8	0.2	5	-	-
Green Peas	0.6–1.0	0.6	1	0.8	0.2	7	0.85	1.6
Lentils	0.5–1.0	0.5	1	0.75	0.3	-	0.737	1
Corn (grain, silage)	1.0–1.7	1	1.7	1.35	0.4	10	0.889	2.4
Spring Wheat	1.0–1.5	1	1.5	1.25	0.3	10	1.038	3

Mitchel, I., Christensen, A., Smith, B., Drozdowski, B. (2018). Agronomic Receptor Evaluation for Direct Soil Contact. Millennium EMS Solutions Ltd. & InnoTech Alberta Report 18-00434 prepared for Petroleum Technology Alliance of Canada (PTAC). 39 pp.

[1] United States Department of Agriculture (2016); [2] Alberta Agriculture and Forestry (2016).

Rooting Characteristics of Native Grassland Species in Saskatchewan

	Soil zone (including topographic position and texture)										
	Brown			Dark Brown						Black	
Species	Level (loam)	Knoll (loam)	Lower slope (loam)	Level (loam)	Level (sand)	Knoll (loam)	Lower slope (loam)	South slope (loam)	North slope (loam)	Level (loam)	Level (gravel subsoil)
Grasses											
Stipa comata	1.1	0.99		0.63	1.07			0.85			
Stipa spartea var. curtiseta		1.27	1.02	0.85		0.6	0.68	1.05	0.8	0.8	1.4
Agropyron smithii	1.27		1.37		0.68	1.65	1.52	1.55			
Agropyron dasystachyum		1.52	1.42	1.12		1.22	1.42	1.3	1.15	1.1	
Bouteloua gracilis	0.85	0.75			0.9	0.38	0.75	0.6	0.4	0.53	
Koeleria cristata	0.6	0.75			0.65	0.33	0.6	0.6		0.58	0.65
Festuca scabrella				1.02			0.6		0.68	0.8	1.1
Carex eleocharis	0.65	0.68			0.35	0.35	0.5	0.6		0.38	0.65
Forbs											
Artemisia frigida	1.47	1.02		0.81	0.88	0.51	1.47	0.78	0.66	0.66	
Phlox hoodii	0.68	0.66			0.41	0.3	0.76	0.56	0.41		
Anenome patens var. wolfgangiana		0.61	0.78	0.91		0.48	0.86	0.68	0.51	0.81	1.22
Gutierrezia diversifolia	0.93	1.3				0.51	0.66	0.51	0.86		

Coupland and Johnson (1965)

12.0 APPENDIX D - NATURAL REGIONS OF SOUTHERN AND CENTRAL ALBERTA

Natural Regions and Subregions in Southern and Central Alberta (Downing and Pettapiece, 2006)

Natural Region	Natural Subregion	Percent of Province	Elevation (average asl)	Terrain	Soil	Vegetation
Grassland	Dry Mixed grass	7.1	800	Undulating plains; till with lacustrine, fluvial, eolian materials	Brown Chernozems; Brown Solonetz; wetlands are Gleysols	This sheet
	Mixed grass	3	975	Undulating plains with rolling to hummocky areas; till and lacustrine materials	Dark Brown Chernozems; wetlands are Gleysols	Mainly agricultural; native grasslands are needle and thread, porcupine grass, northern and western wheatgrass; buckbrush shrublands
	Northern Fescue	2.3	800	Undulating plains and hummocky uplands; till with lacustrine, fluvial, and eolian materials	Dark Brown Chernozems; Dark Brown Solonetz; wetlands are Gleysols	Plains rough fescue (moist), western porcupine grass (drier); buckbrush and rose shrublands; grass wetlands
	Foothills Fescue	2.1	1100	Hummocky and rolling to undulating; till, lacustrine deposits	Black Chernozems, wetlands are Gleysols	Mountain rough fescue on moister sites, western wheatgrass on drier sites; wet areas often shrubby
Parkland	Foothills Parkland	0.6	1250	Sloping lower foothills and hummocky uplands; till with lacustrine materials in valleys.	Black Chernozems, some Dark Grey Chernozems; wetlands mainly Gleysols	Aspen forests; areas of dense tall willow (north); grasslands (mountain rough fescue and Parry's oatgrass) more common on southerly slopes
	Central Parkland	8.1	750	Undulating plains, hummocky uplands; glacial till with lacustrine, fluvial, and eolian inclusions	Black Chernozems, some Dark Gray Chernozems; Solonetzic soils; wetlands are Gleysols	Extensively cultivated; aspen interspersed with grasslands dominated by plains rough fescue; tree cover increases with latitude; graminoid
	Pace River Parkland	0.5	625	Gently undulating plains, south-facing slopes of the Peace River; lacustrine deposits with colluvium on slopes	Dark Gray to Black Chernozems (often Solonetzic); Solonetzic and Luvisolic soils; slopes are Regosols and Dark Brown Chernozems; wetlands mainly Gleysols	Mostly cultivated; remnant aspen clones and continuous forest, interspersed with sedge–California oat grass–porcupine grass; Jack pine on sands; graminoid wetlands, often ringed by

Natural Region	Mean annual temperature (°C)	Mean temperature, warmest month (°C)	Mean temperature, coldest month (°C)	Growing degree days >5°C	Mean annual precipitation (mm)
Grassland	4	17.8	-11.7	1592	374
Parkland	2.3	16.4	-14.4	1391	447

Grassland Natural Region - Dry Mixed grass Natural Subregion, Mixed grass Natural Subregion, Northern Fescue Natural Subregion, Foothills Fescue
Parkland Natural Region - Foothills Parkland Natural Subregion, Central Parkland Natural Subregion, Peace River Parkland

13.0 APPENDIX E - GLOBAL METHANE BUDGET

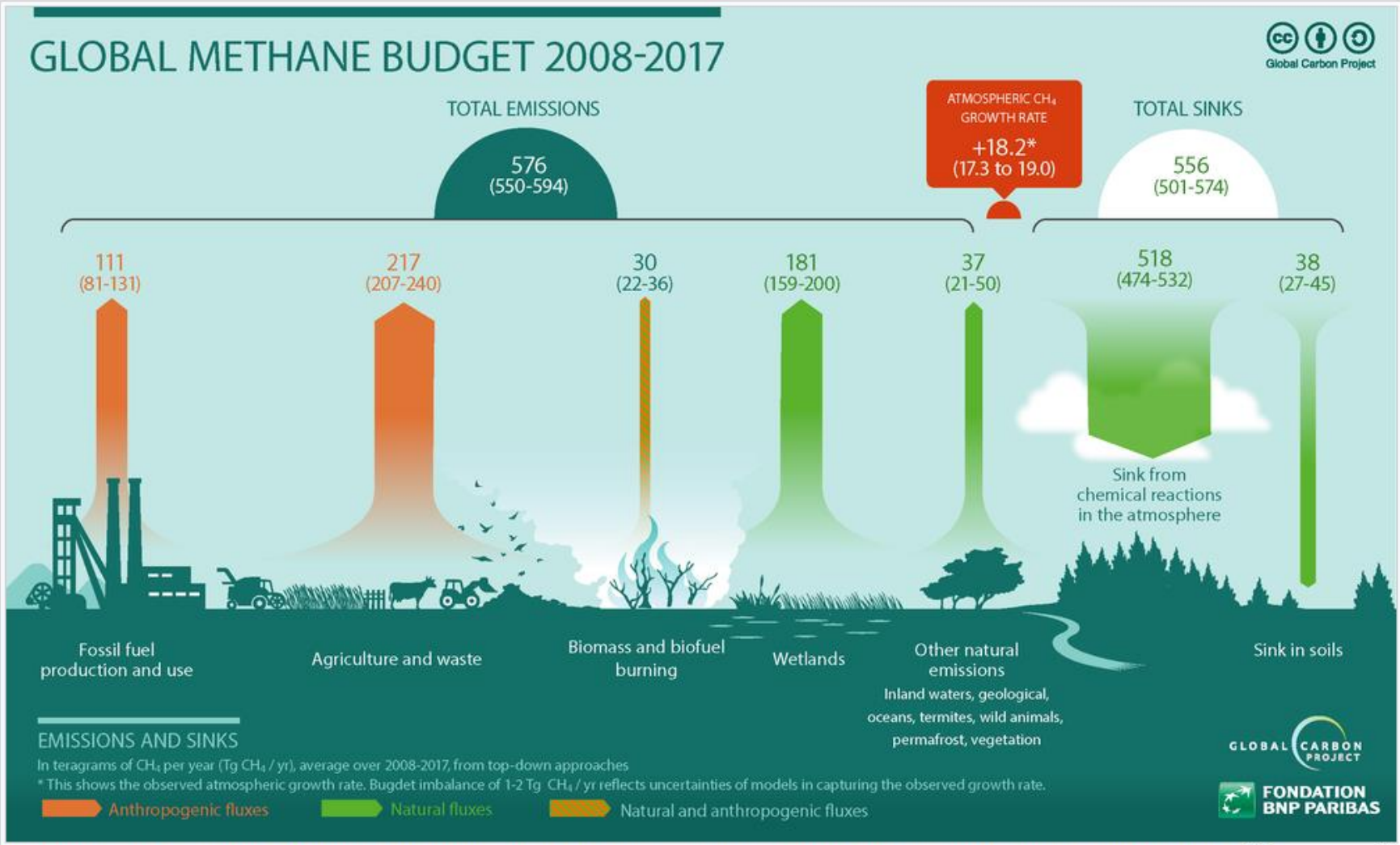


Diagram showing the main sources of methane for the decade 2008-2017, produced by a global report on global methane emissions by the Global Carbon Project[31]