UNIVERSITY OF CALGARY

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CESAR
CANADIAN
ENERGY SYSTEMS
ANALYSIS RESEARCH

Scenarios for Alberta's Energy Future

Monday, December 7, 2015 from 3:30 to 5:30 pm

Acadia Room, Calgary Marriott Downtown, 110 9th Avenue SE, Calgary

Thanks to the generous support from the Energy Futures Laboratory, and contributions of data resources from whatIf? Technologies Inc, and CESAR, we are pleased to provide a selection of Posters highlighting the work of University of Calgary students registered in the Scie529 course, part of the Energy Specialization in the Faculty of Science.

Instructors:

Dr. David B. Layzell, FRSC (Course Coordinator) Professor and Director, CESAR
Dr. Bastiaan Straatman, CanESS Modeller, CESAR

Molten Carbonate Fuel Cells for SAGD

Transitioning Alberta's Oil Sands and Electricity Grid for a Low Carbon Energy Future


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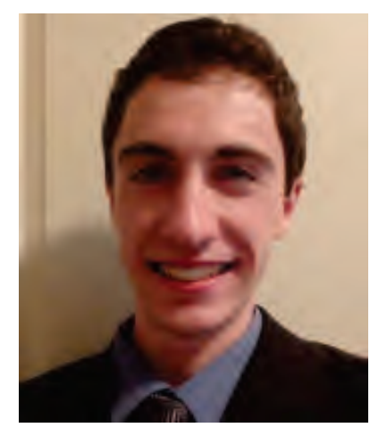
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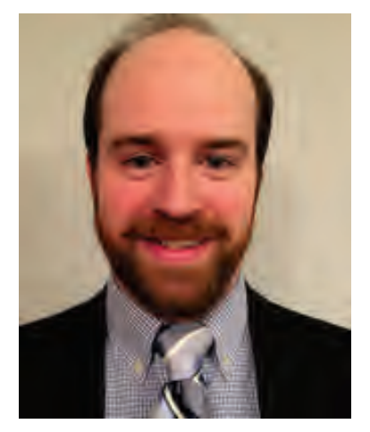
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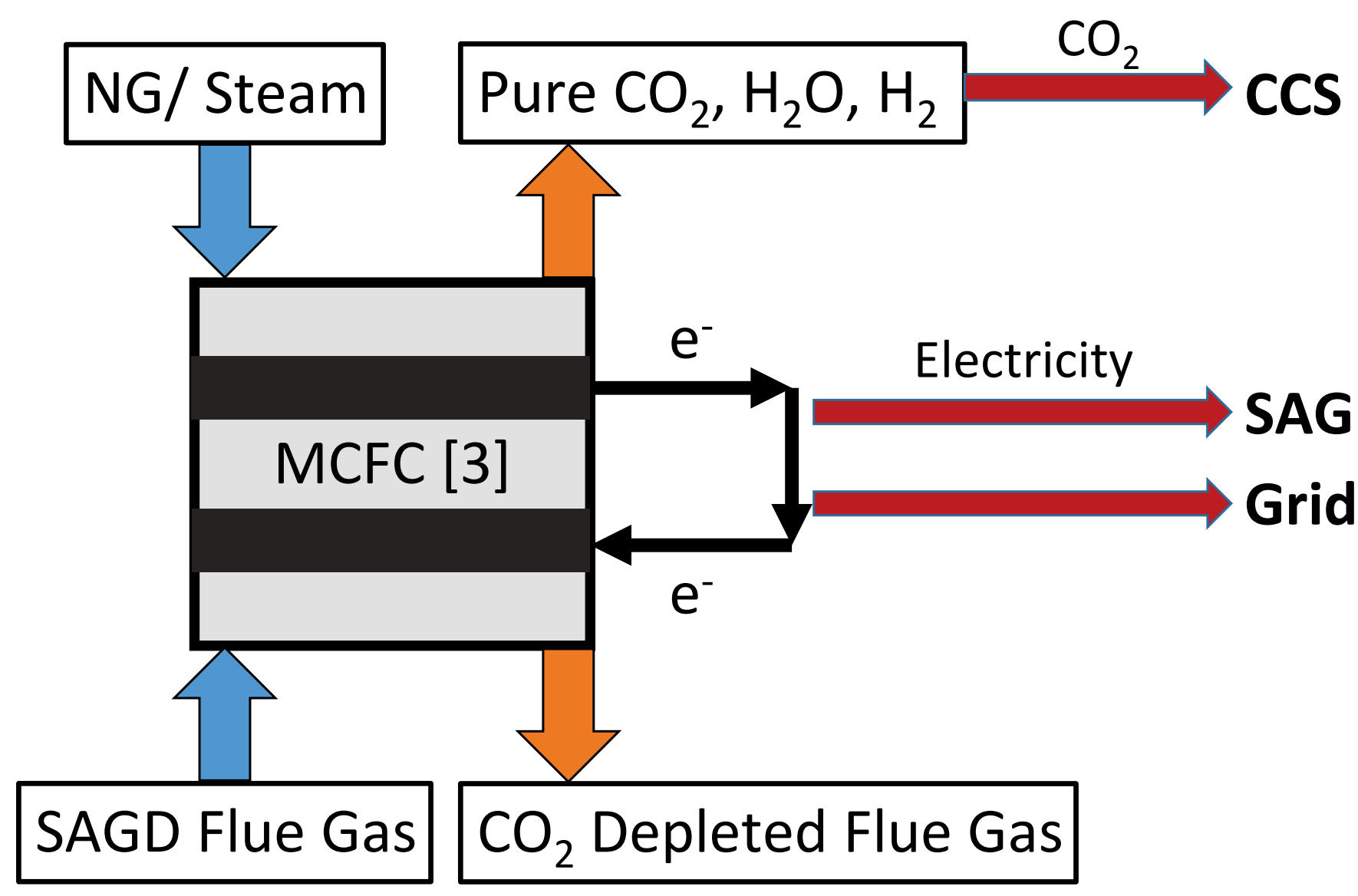
INTRODUCTION

Greenhouse gas (GHG) emissions from Steam Assisted Gravity Drainage (SAGD) of over 24 Mt CO2e/yr (76 kg CO_2e/bbl) have undermined public support for both oil sands development and market access. The resulting adverse economic impacts are driving the need for technologies to greatly reduce the CO_2 footprint associated with oil sands recovery.

Molten carbonate fuel cells (MCFC) have been proposed [1,2] for integration into SAGD facilities where they could:

- Capture 90% of the CO2 emissions associated with SAGD steam generation (OTSG)
- Provide a low GHG source of electricity for SAGD
- Supply surplus low GHG power to the coal dominated Alberta electrical grid

This study will explore the system level potential of the MCFC technology.



METHODS

Assumptions:

- Low growth oil sands model
- MCFC capture of 90% CO_2 from flue gas (higher possible) [2]
- Alternative scenario includes CO_2 compression needs [2]

Parameter	Value
Reference Facility Output	33,000 (bbl/day) [2]
SAGD Steam Oil Ratio	3 (bbl H_2O/bbl)
MCFC Size	76 MW [2]
Coal Emission Factor	1020 (kg CO_2e/MWh)
NG-SC Emission Factor	500 (kg CO_2e/MWh)
NG-CC Emission Factor	380 (kg CO_2e/MWh)
SAGD Emission Factor	76.3 (kg CO_2e/MWh)

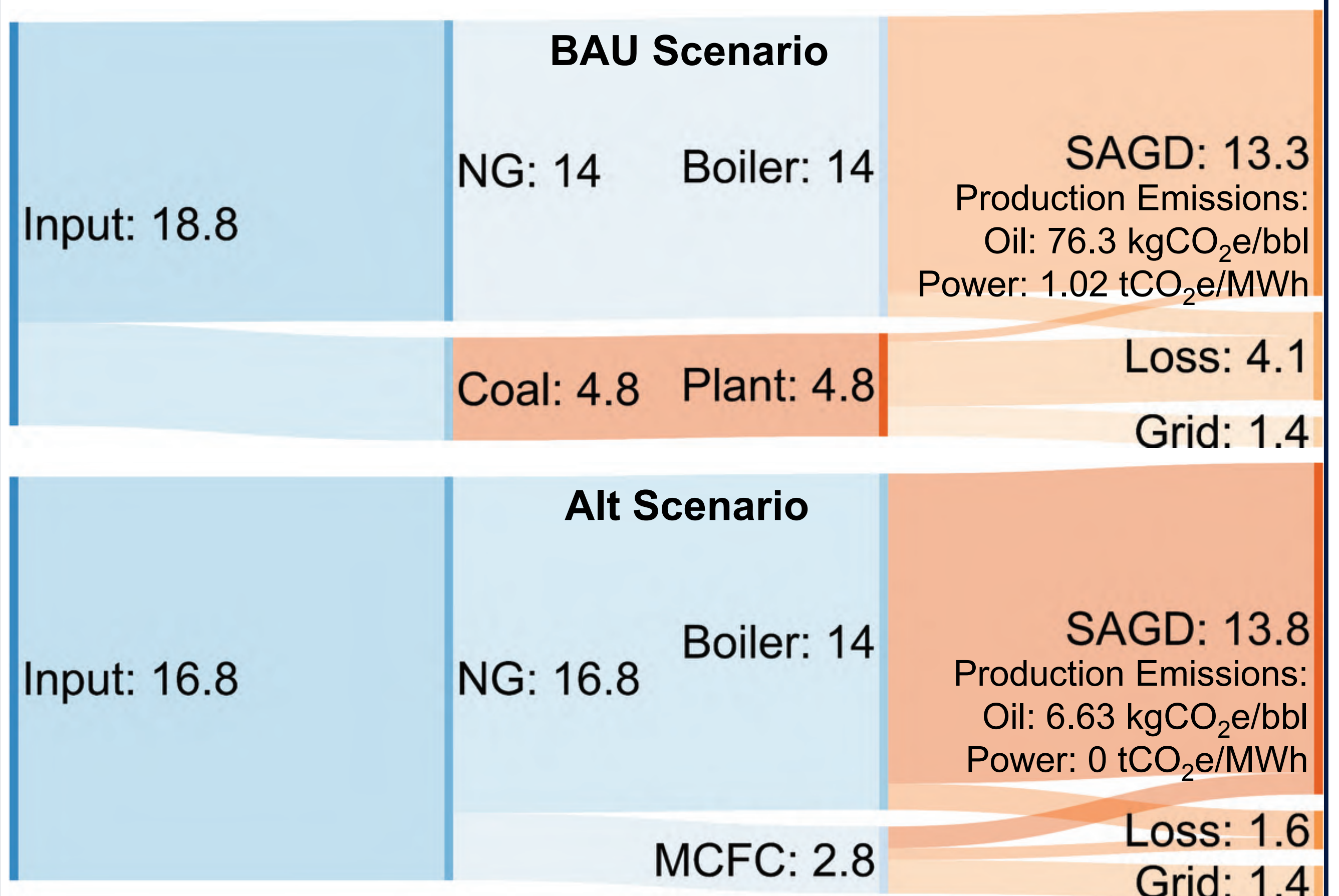


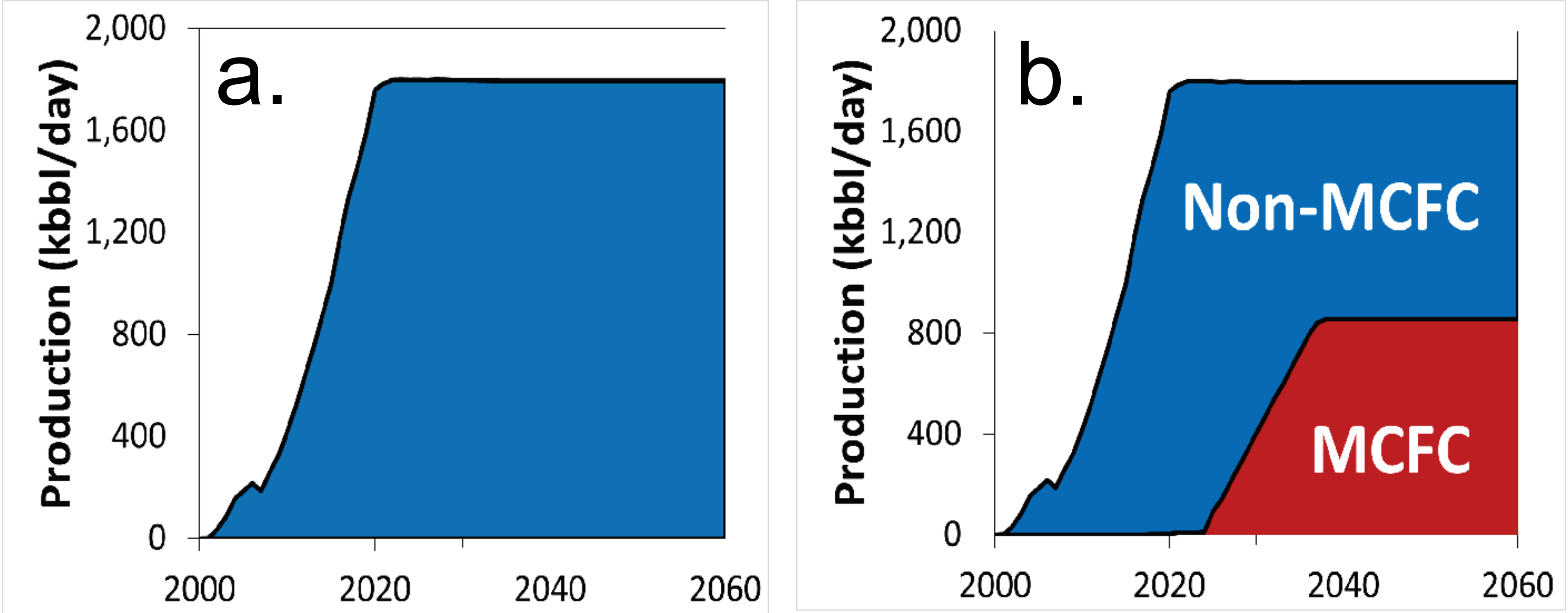
Fig 2. Energy Comparison for BAU vs. Alt Scenario, Single 33,000 bbl/day Facility, in PJ/yr

RESULTS

Business-as-Usual MCFC + SAGD

Fig 3. SAGD Crude Production

SAGD Production (kbbl/day annually): MCFC-integrated facility production shown in red

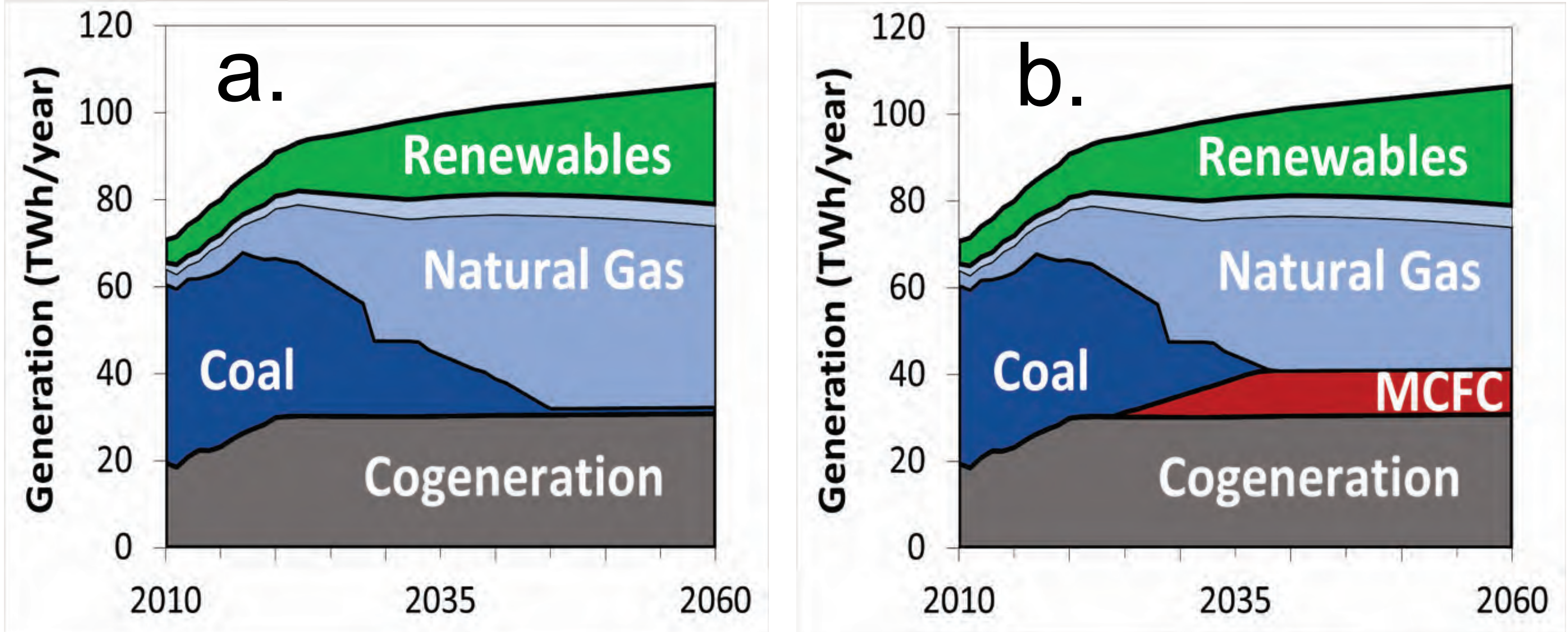


NOTE:

- MCFCs installed on 27 facilities by 2037

Fig 4. Alberta Electricity Demand

Demand generation broken down by fuel type for both scenarios

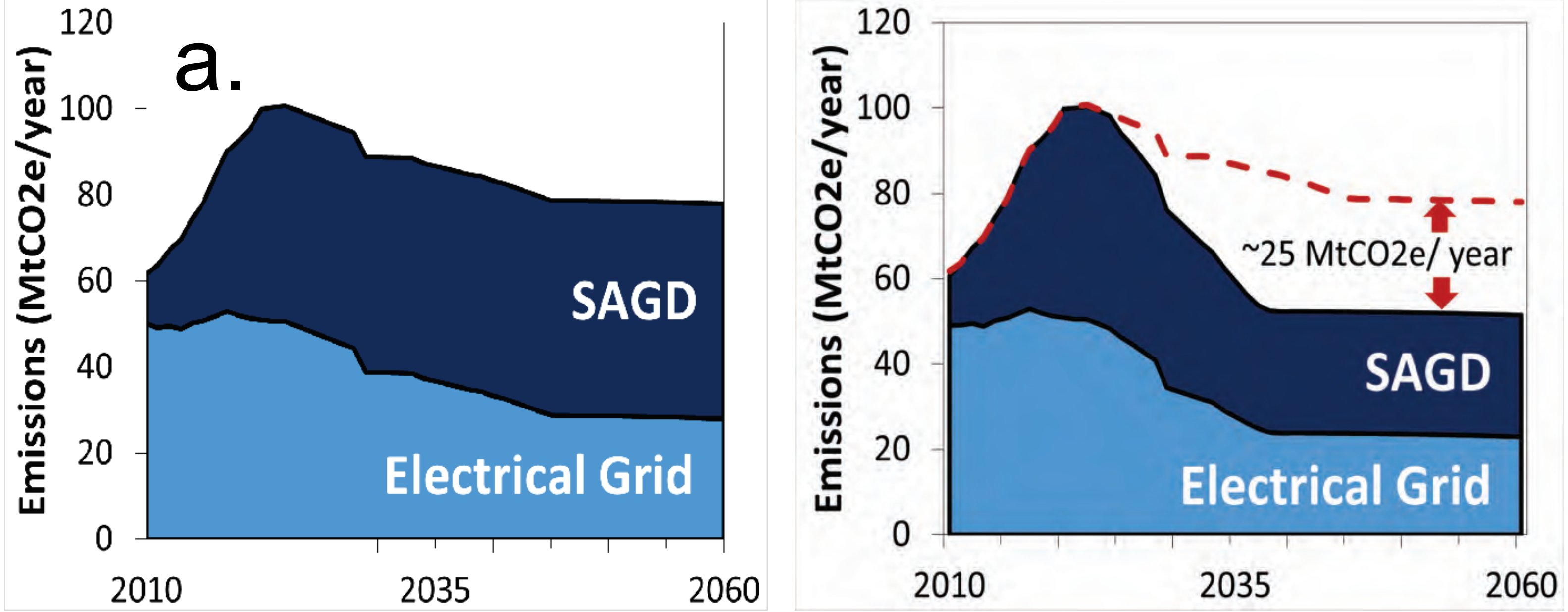


NOTE:

- MCFC Excess Power displaces coal power

Fig 5. Total Emissions Reductions

GHG Savings based on SAGD Carbon-capture with MCFCs as well as MCFC-derived electrical generation

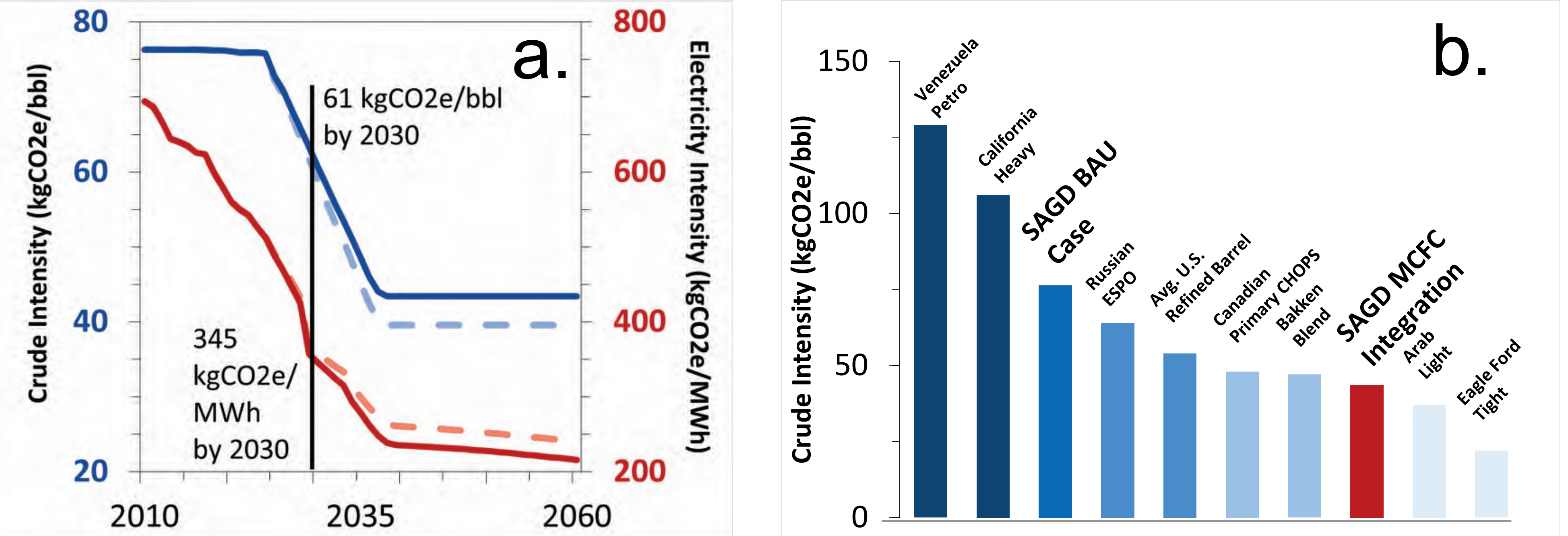


NOTE:

- Emissions decline due to SAGD CCS and coal power replacement

Fig 6. CO2 Emissivity of SAGD Crude

Emissions decline over time due to SAGD CCS and coal power replacement by net MCFC power generation.



DISCUSSION

This study investigates the emission reductions and costs associated with the integration of MCFC across the SAGD industry using scenario modelling [5, 6, 7, 8, 9, 10].

MCFCs could be retrofitted to process the OTSG flue gas from 27 SAGD standard facilities by 2037, accounting for up to 891,000 bbl/day of production. Subsequent net power generated by SAGD MCFCs would be exported to the grid to offset demand met by coal-fired power plants and combined-cycle natural gas plants, accounting for ~20 TWh/year of demand. Overall SAGD and grid emissions would be reduced by ~25 Mt CO2e/year. The resulting would be among the lowest emissivity crude in North America.

A carbon tax of $15-20/tCO2e by 2030 will account for the total costs of MCFCs and additional financial risk associated with their deployment and operation.

Limitations of study:

- Low oil sands growth model – No new facilities.
- Technology adoption and cost reductions predicted by FCE Inc. – Sole North American MCFC Manufacturer
- All SAGD facilities modelled as 'COSIA Standard'

CONCLUSIONS

Integrating MCFCs into SAGD facilities has the potential to cut SAGD and electrical grid emissions while promoting early coal-fired power plant retirement in Alberta. Following the deployment model given will reduce emissions by **865** Mt CO_2e to 2060.

This study recommends:

- Proactive **investment** in MCFC technology to set up pilot plant trials
- **Fast-tracking** of approvals and regulation process surrounding MCFC to bolster deployment
- Implementation of **carbon accounting system** allowing transfer of emissions between oil sands and electrical grid for ultra-low emissivity bitumen production

These will allow the full potential of MCFC integration in SAGD to be reached.

REFERENCES

[1] COSIA Challenge, "Natural Gas Decarbonization," COSIA, 2015.
[2] Consultancy, Jacobs, "Evaluation of Integrating a Molten Carbonate Fuel Cell (MCFC) with a SAGD Facility," Jacobs Consultancy, July 2015.
[3] J. Giovannetti and J. Jones, "Alberta Carbon Plan a Major Pivot in Environmental Policy," *The Globe and Mail,* 22 November 2015.
[4] A. M. Sears, "Changes to the regulation of greenhouse gas emissions in Alberta: The Government of Alberta announces first step in new climate change strategy," Strikeman Elliott, 26 June 2015. [Online]. Available: http://www.canadianenergylaw.com/2015/06/articles/climate-change/changes-to-the-regulation-of-greenhouse-gas-emissions-in-alberta-the-government-of-alberta-announces-first-step-in-new-climate-change-strategy/. [Accessed 3rd October 2015].
[5] FuelCell Energy, "White Paper: Carbon Capture Using Direct FuelCell Systems," FuelCell Energy, 2013. [Online]. Available: http://www.fuelcellenergy.com/assets/DFC-Carbon-Capture-WhitePaper.pdf. [Accessed 3rd October 2015]. [11] P. C. G. M. Stefano Campanari, "CO2 capture from combined cycles integrated with Molten Carbonate Fuel Cells," International Journal of Greenhouse Gas Control, vol. 4, pp. 441-451, 2010.
[6] R. Remick and D. Wheeler, "Molten Carbonate and PhosphoricAcid Stationary Fuel Cells: Overview and Gap Analysis," National Renewable Energy Laboratory, 2010.
[7] R. H. S. S. D. Butler, "Application of Molten Carbonate Fuell Cell for CO2 Capture in Thermal In Situ Oil Sands Facilities," International Journal of Greenhouse Gas Control, vol. 41, pp. 276-284, 2015.
[8] P. C. G. M. S. B. S. Campanari, "Economic analysis of CO2 capture from natural gas combined cycles using Molten Carbonate Fuel Cells," Applied Energy, vol. 130, pp. 562-573, 2014.
[9] Jacobs Consultancy, "Evaluation of Solid Oxide Fuel Cells for Combined Heat and Power at a SAGD facility," Jacobs Consultancy, 2014.
[10] Jacobs Consultancy, "ECM Evaluation Study Report for Alberta Innovates," Jacobs Consultancy, 2013.

ACKNOWLEDGEMENTS

The authors would like to thank Whatif? Technologies for the use of their CanESS model in this work. Thanks are also due to our expert advisors Dr. Song Sit and Dr. Viola Birss. Lastly, we would like to thank Dr. David Layzell and Dr. Bas Straatman for their input and guidance.

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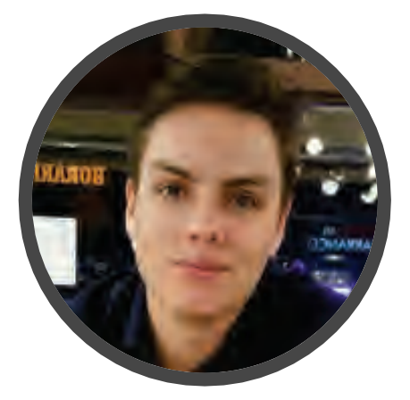
Carbon Black to the Future?

Can natural gas dissociation provide a clean fuel for SAGD and a high value by-product?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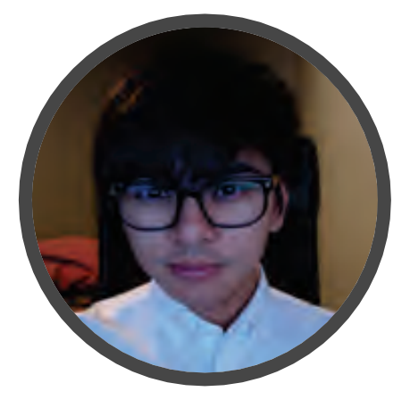
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INTRODUCTION

Alberta has vast reserves of natural gas (NG) that are used throughout our energy systems, including Steam Assisted Gravity Drainage (SAGD) for oil sands recovery. SAGD is projected to emit ~50 Mt of CO_2e/yr by 2020 [1]. Natural Gas Decarbonisation (NGD) via microwave plasma technologies were investigated in this study as a strategy to reduce the carbon footprint of SAGD bitumen recovery. These technologies produce H_2, a CO_2-free fuel source, and $C_{(s)}$, carbon black (CB) a potentially high value by-product. The processes by Atlantic Hydrogen (AHI) and Monolith Materials were considered [2,3].

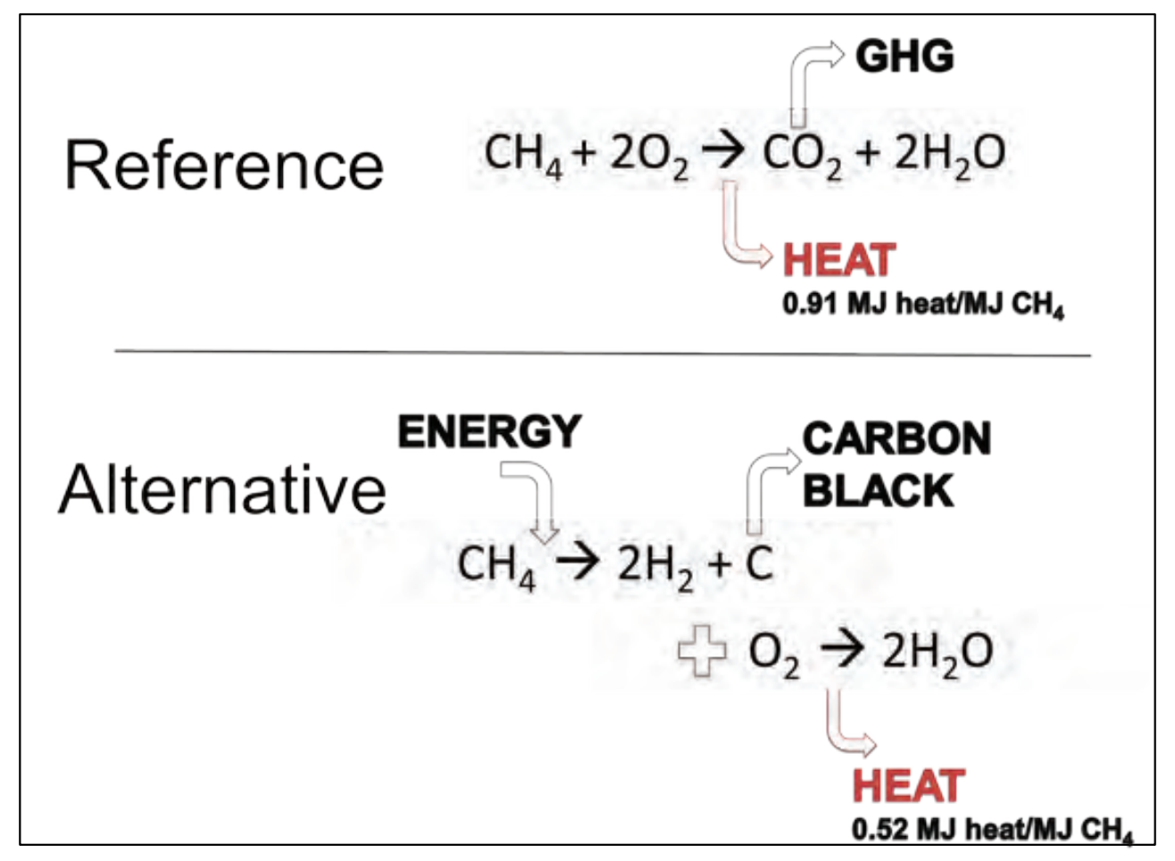


Fig. 1. BAU heat generation process, vs. methane decarbonization.

METHODS

Business as usual (BAU) and alternative scenarios (AS) were modelled for SAGD energy use and emissions in Alberta.

BAU assumed "low oil sands growth" derived from the CanESS model [1]. SAGD energy and emissions retrieved from a standardized 33 kbpd facility from COSIA [4].

The AS scaled a NGD to provide H_2 for a 33 Mbpd operation. Yields, inputs, economics and deployment were modelled off available industry data and process literature [2-6]. The scenario assumed 50% adoption by 2060.

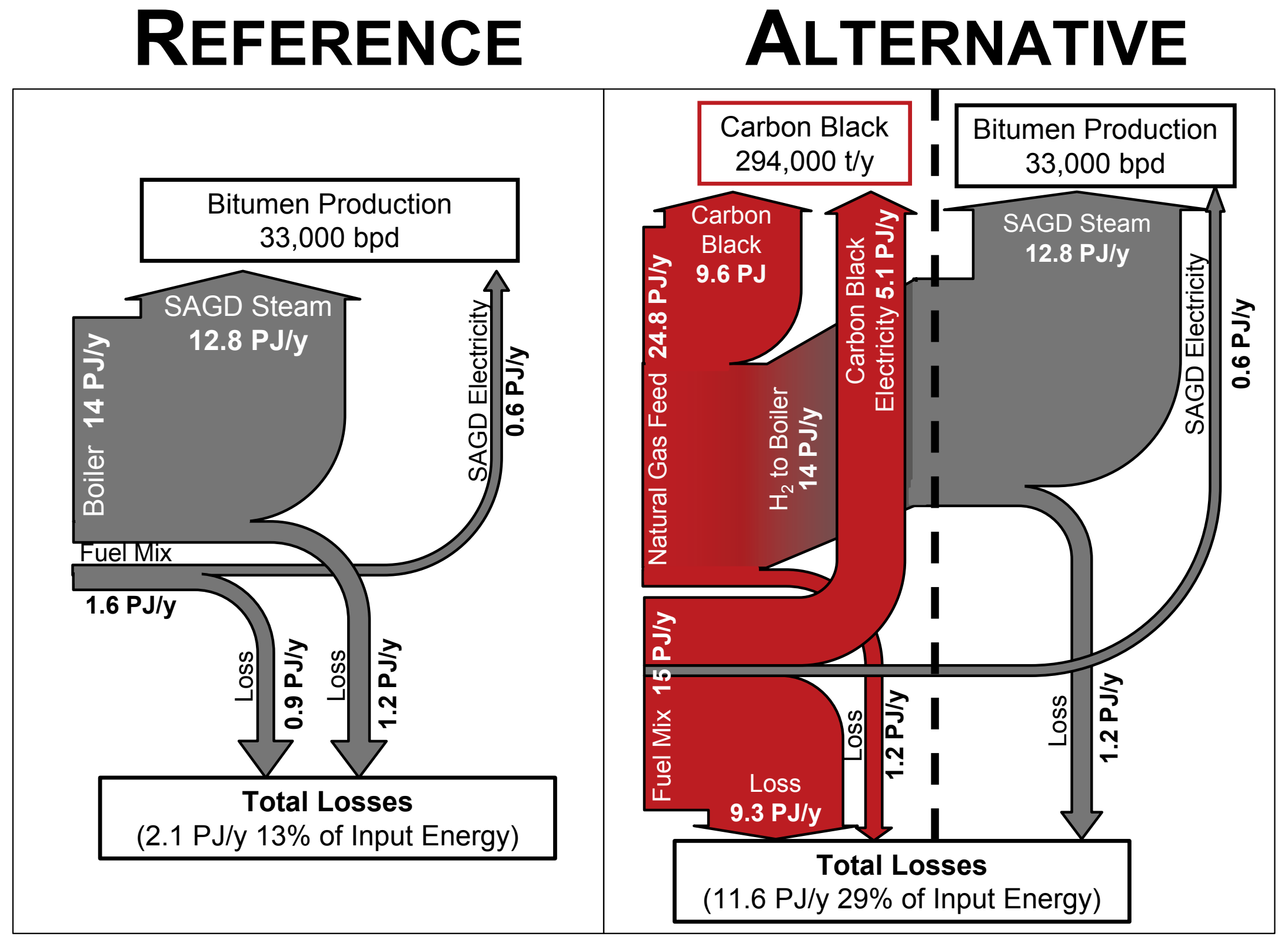


Fig. 2. Energy flow the BAU and Alternative scenario SAGD plant.

RESULTS AND DISCUSSION

A. Energy Demand Comparison

BAU SAGD energy demand compared with energy demands to run SAGD while producing Carbon Black and Hydrogen. Demonstrates total energy demand in EJ/yr.

B. CO2 Emission Comparison

Decarbonization will reduce SAGD emissions. However the CB process emissions will limit this reduction.

C. CO2 Emission Intensity

The emissions per barrel of bitumen can be greatly reduced by implementing NGD.

D. Carbon Black Market and Economics

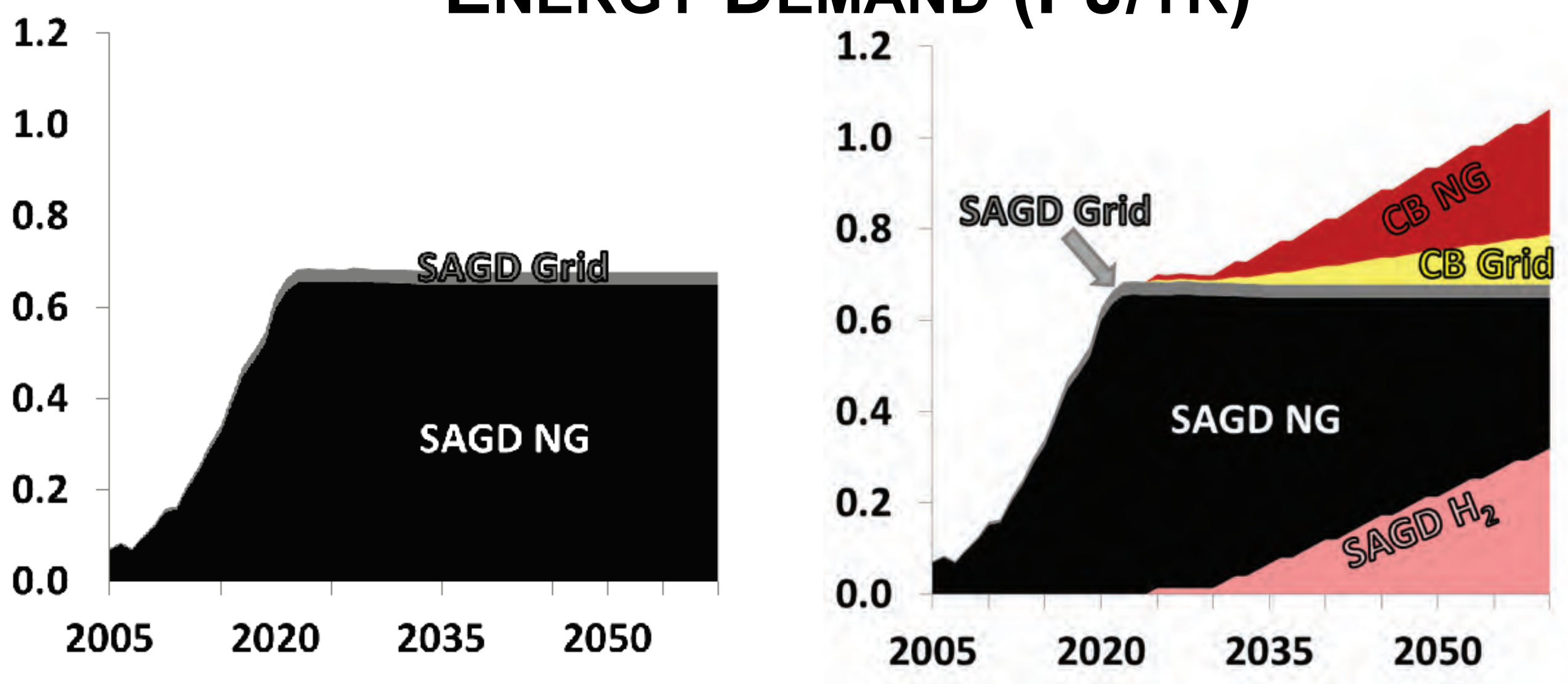
The market is expected to increase in the future. However economics of NGD highly sensitive to CB price.

E. Other Carbon Black Markets

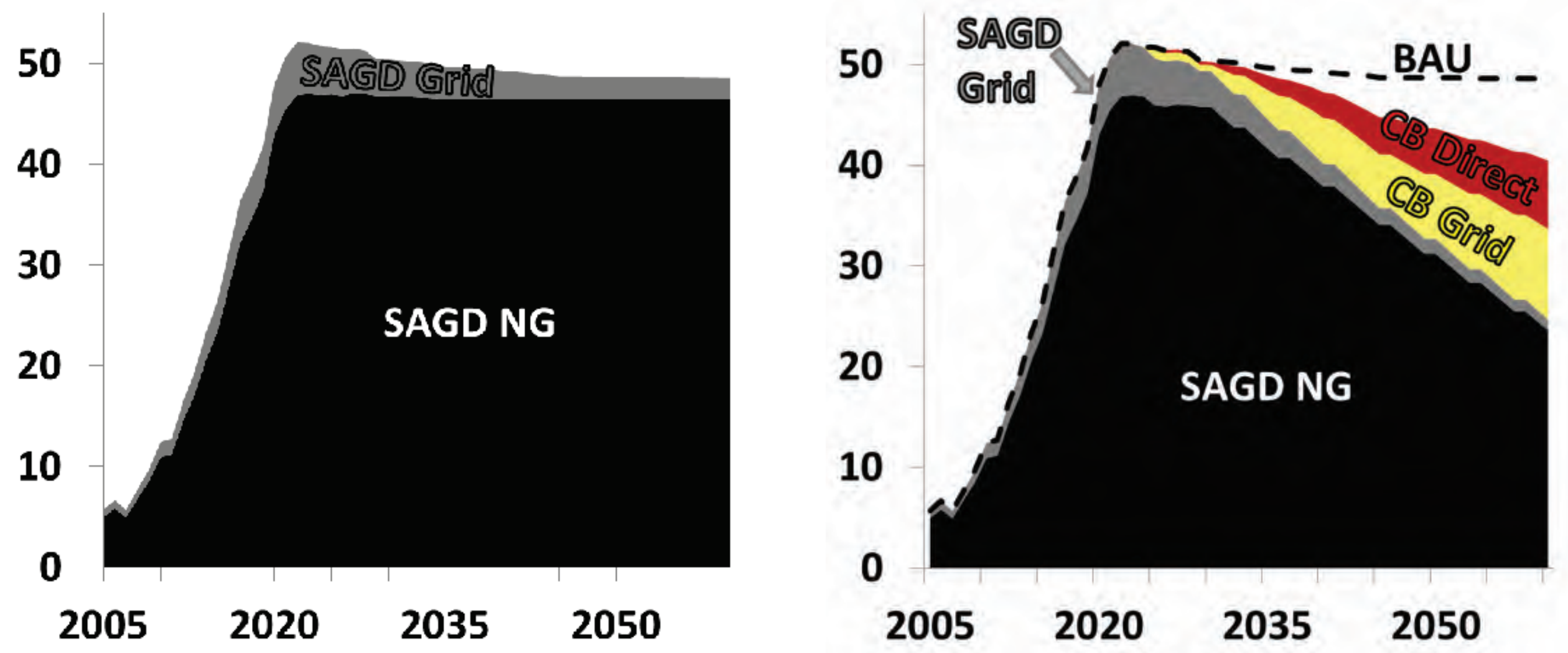
Carbon can be converted into other useful forms such as Graphene.

REFERENCE ALTERNATIVE

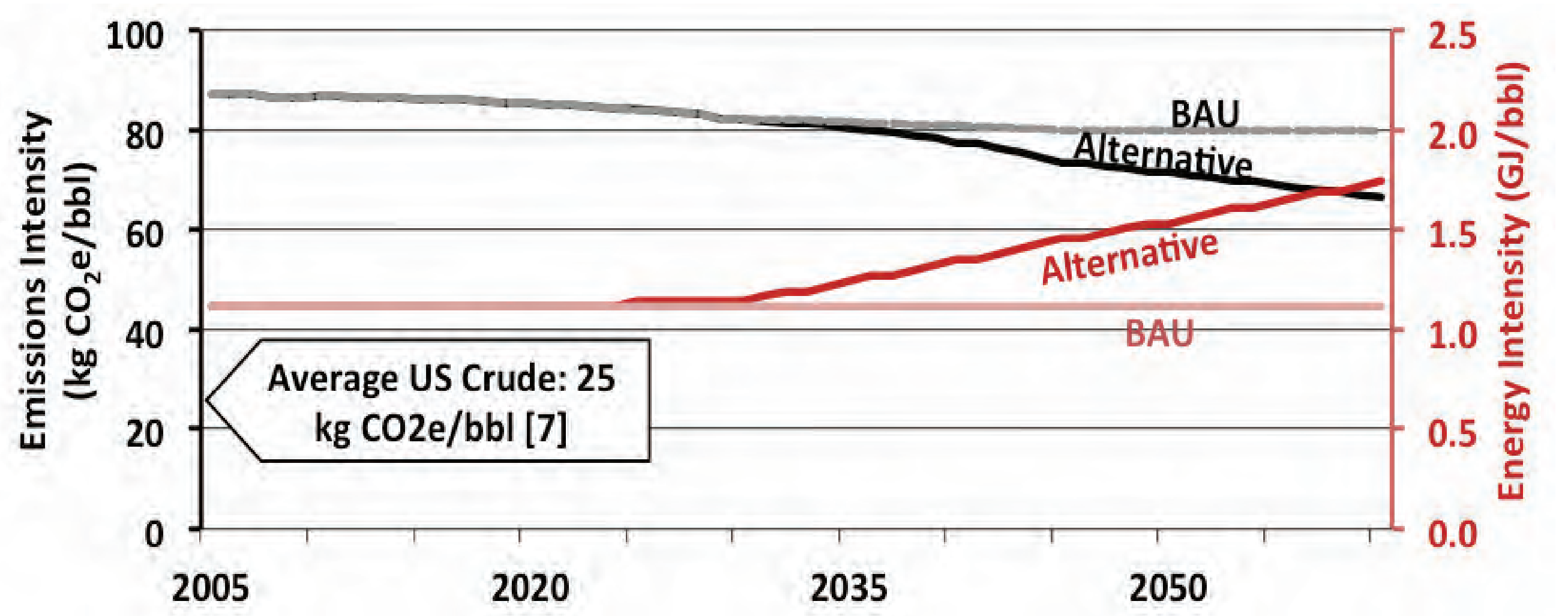
ENERGY DEMAND (PJ/YR)

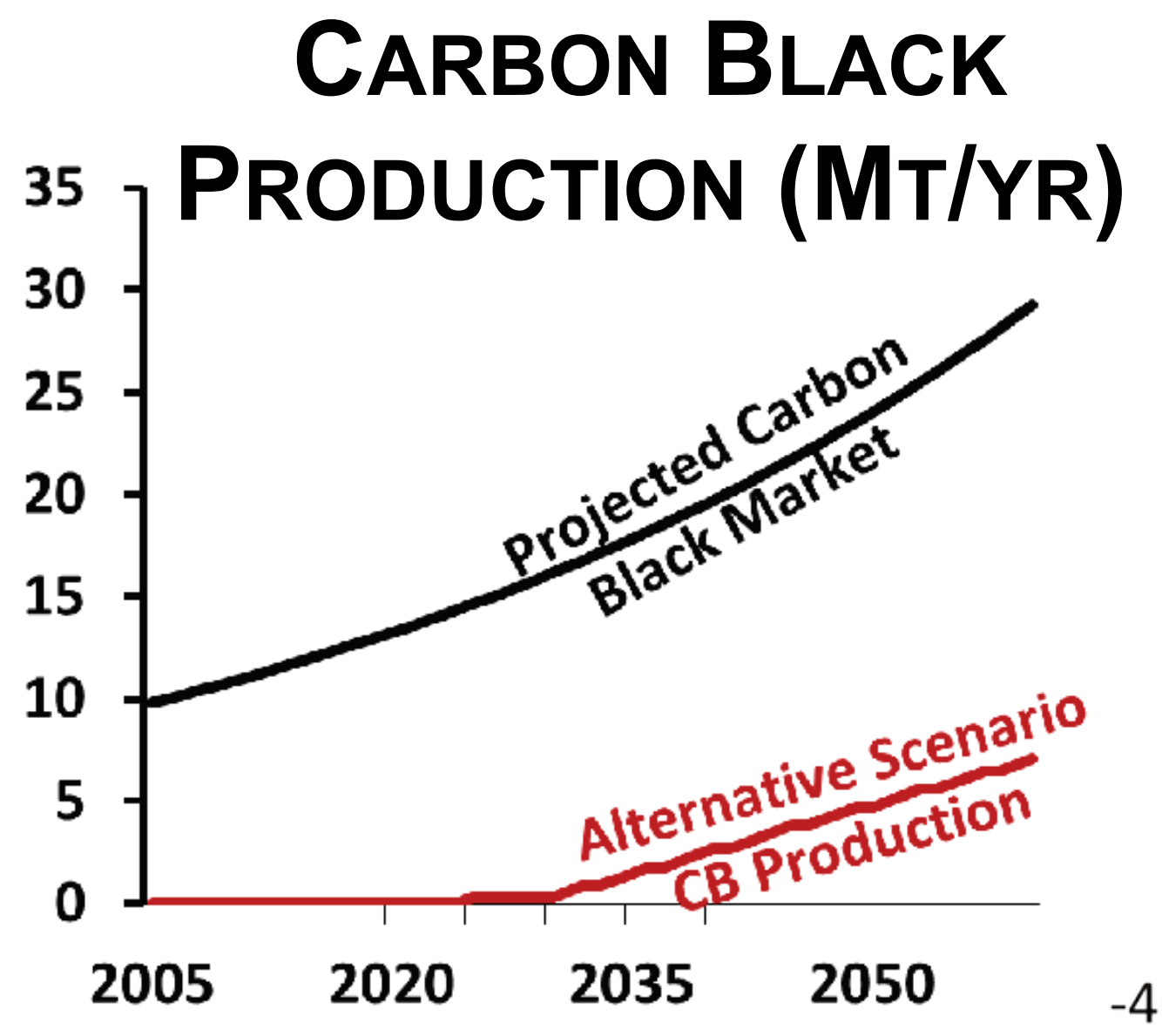


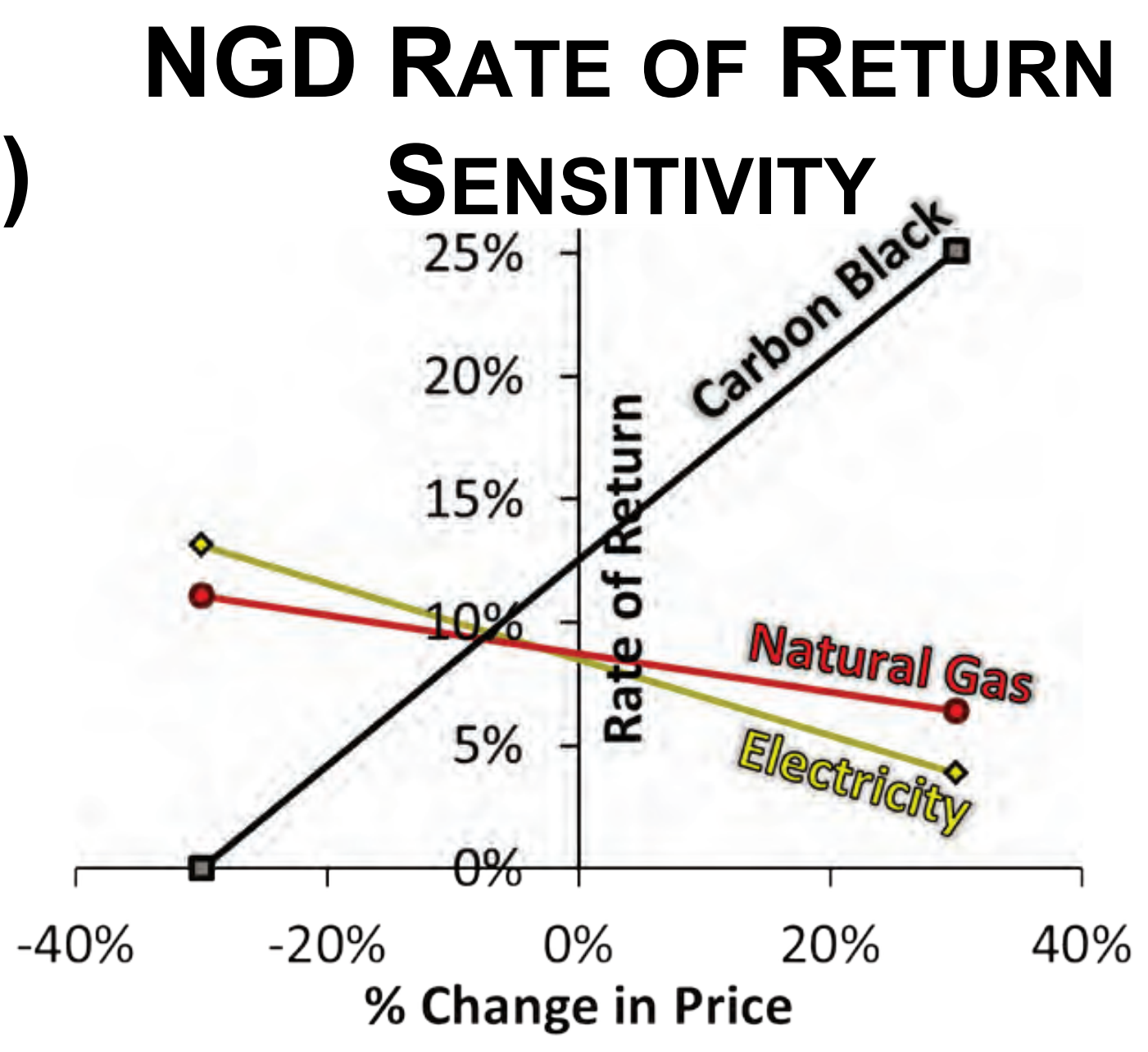
CO_2 EMISSIONS (MT/YR)



ENERGY AND EMISSIONS INTENSITY







Present Carbon Black markets and Applications [8,9]	Future Carbon Black Markets and Applications [8,9]
Tires	Production of Graphene, Buckminsterfullerenes, Carbon nanotubes
Synthetic Rubber and Plastics	High Carbon Steel Production
Electrostatic Discharge (ESD) Compounds	Carbon Black in Material, Chemical and Electric Industry
High Performance Coatings	Carbon based Electric Transmission Sources, Batteries and Capacitors

- NGD integration would require an increased ~0.4EJ/yr
- Increase is equivalent to the yearly usage of 1.3 million people

- Potential for reduction of ~8 Mt/yr from BAU
- A more efficient decarbonisation technology would further lower emissions

- Average Oil Sands per barrel emissions will decrease by 25%
- This decrease is still far from reaching average conventional crude emissions

- With 50% of SAGD creating Carbon Black, approximately ¼ of the future CB market demand would be met.

- New CB markets like carbon fiber or graphene will be necessary to utilize increased CB production

CONCLUSIONS

NGD is a potentially viable pathway to significantly reduce CO_2 emissions of SAGD in Alberta. This study *indicated a 8 Mt/y reduction in CO_2 emissions for microwave plasma based NGD by 2060*. That said, the high electrical demand of this technology is a significant barrier to its adoption.

Research into the following areas should be considered:

- *Less energy intense solutions* such as those being investigated by Drs. Nduagu and Gates at the University of Calgary [10,11].
- *Developing new CB products* to expand the currently mature market
- *Evaluating the potential for large scale energy storage* by converting CB into graphene super capacitors

ACKNOWLEDGEMENTS

We would like to thank our technical advisors Experience Nduagu and David Foord (AHI) as well as Dr. Bastiaan Straatman and Dr. David Layzell for directional guidance. We would also like to thank whatIf? Technologies for access and use of the data from their CanESS energy systems model.

REFERENCES

[1] whatIf Technologies Inc., "Canada Energy Systems Simulator (CanESS)," 2014. [Online]. Available: www.caness.ca.

[2] B. Gaudernack and S. Lynum, "Hydrogen from natural gas without release of CO2 to the atmosphere," *Int. J. Hydrogen Energy*, vol. 23, no. 12, pp. 1087–1093, 1998.

[3] Boxer Industries, "Request to Approve Project for Sales and Use Tax Exclusion (STE)," Redwood City, 2013

[4] COSIA, "COSIA Challenge - Natural Gas Decarbonization," 2014. [Online]. Available: www.cosia.ca..

[5] P. L. Johnson, R. J. Hanson, and R. W. Taylor, "Integration of Plasma and Hydrogen Process with Combined Cycle Power Plant and Steam Reformers," 2015.

[6] G. Towler and R. Sinnott, Chemical Engineering Design, 2nd Edition. Elsevier Ltd, 2013.

[7] IHS Energy, "Comparing GHG Intensity of the Oil Sands and the Average US Crude Oil," Special Report, May 2014.

[8] International Carbon Black Association, "Carbon Black Uses." [Online]. Available: http://www.carbon-black.org/index.php/carbon-black-uses. [Accessed: 12-Nov-2015].

[9] A. K. Geim, "Graphene: Status and Prospects," Science, vol. 324, no. 5934, pp. 1530–1534, 2009.

[10] E. I. Nduagu and I. D. Gates, "Process analysis of a low emissions hydrogen and steam generation technology for oil sands operations," Appl. Energy, vol. 146, pp. 184–195, 2015.

[11] E. I. Nduagu and I. D. Gates, "An Ultra-low Emissions Enhanced Thermal Recovery Process for Oil Sands," Energy Procedia, vol. 63, pp. 8050–8061, 2014.

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Biomass Pyrolysis in the Oil Sands

Reducing GHG Emissions of Bitumen Recovery by Integrating Alberta's Forestry Industry


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INTRODUCTION

Steam-Assisted Gravity Drainage (SAGD), an energy intensive oil recovery technique, consumes 335PJ/year for steam production, producing 24 $MtCO_2e$/year [1, 2]. The high GHG footprint has made it the focal point for environmental groups and created barriers for market access.

A possible solution is to pyrolze residual forestry biomass to provide energy for steam generation and simultaneously produce biochar, creating a powerful carbon sink. This study uses scenario to assess the feasibility of bringing together the oil and forestry industries to reduce Alberta's overall emissions. Figure 1 compares the business-as-usual (BAU) and alternative scenarios (Alt).

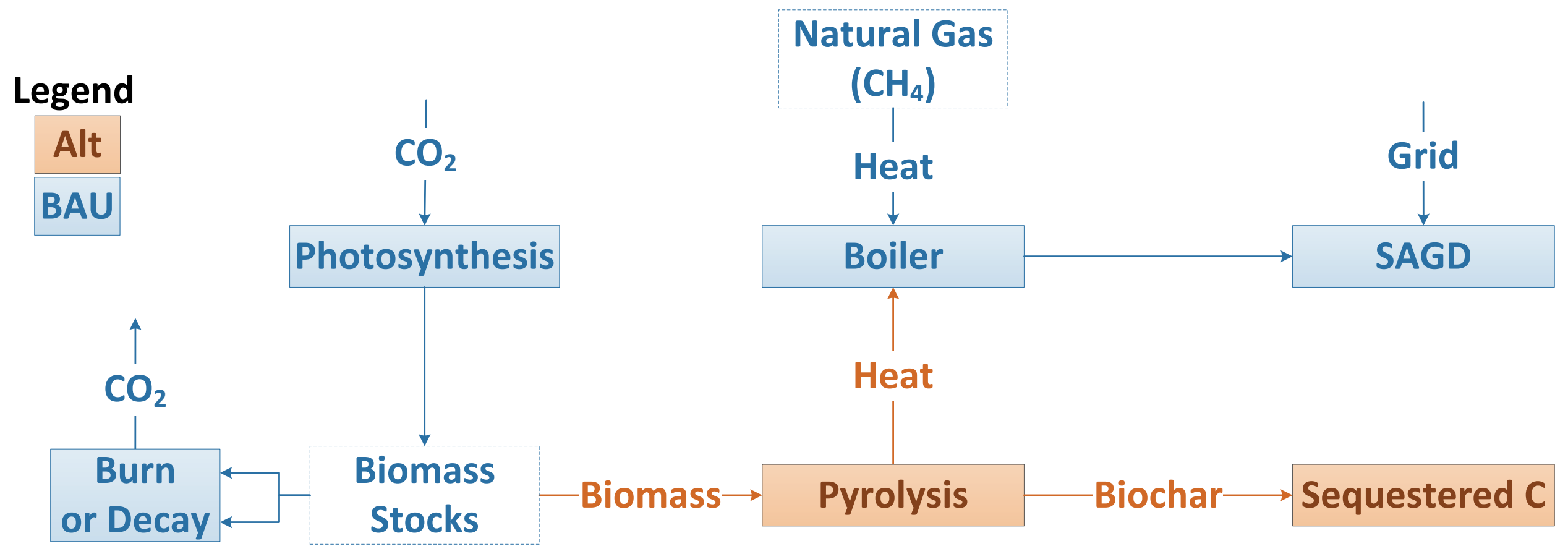


Fig. 1. SAGD Flow Diagram (BAU and Alternative)

METHODS

Assumptions to determine available biomass:

1. All forestry residues within 100km of driving (65km radius) can be collected [2].
2. The facility is in a forested area which is being sustainably harvested year-round.
3. Implementation of a 10% capacity pilot facility by 2019 and a maximum of 7 facilities by 2033 [2].

Note: many conversion factors were used for this project; some of these are listed in the references section.

Economics

The price of carbon was based on the change in operating costs and added transportation between the BAU and Alt scenarios. Savings from natural gas and emissions reductions were also accounted for [7-9].

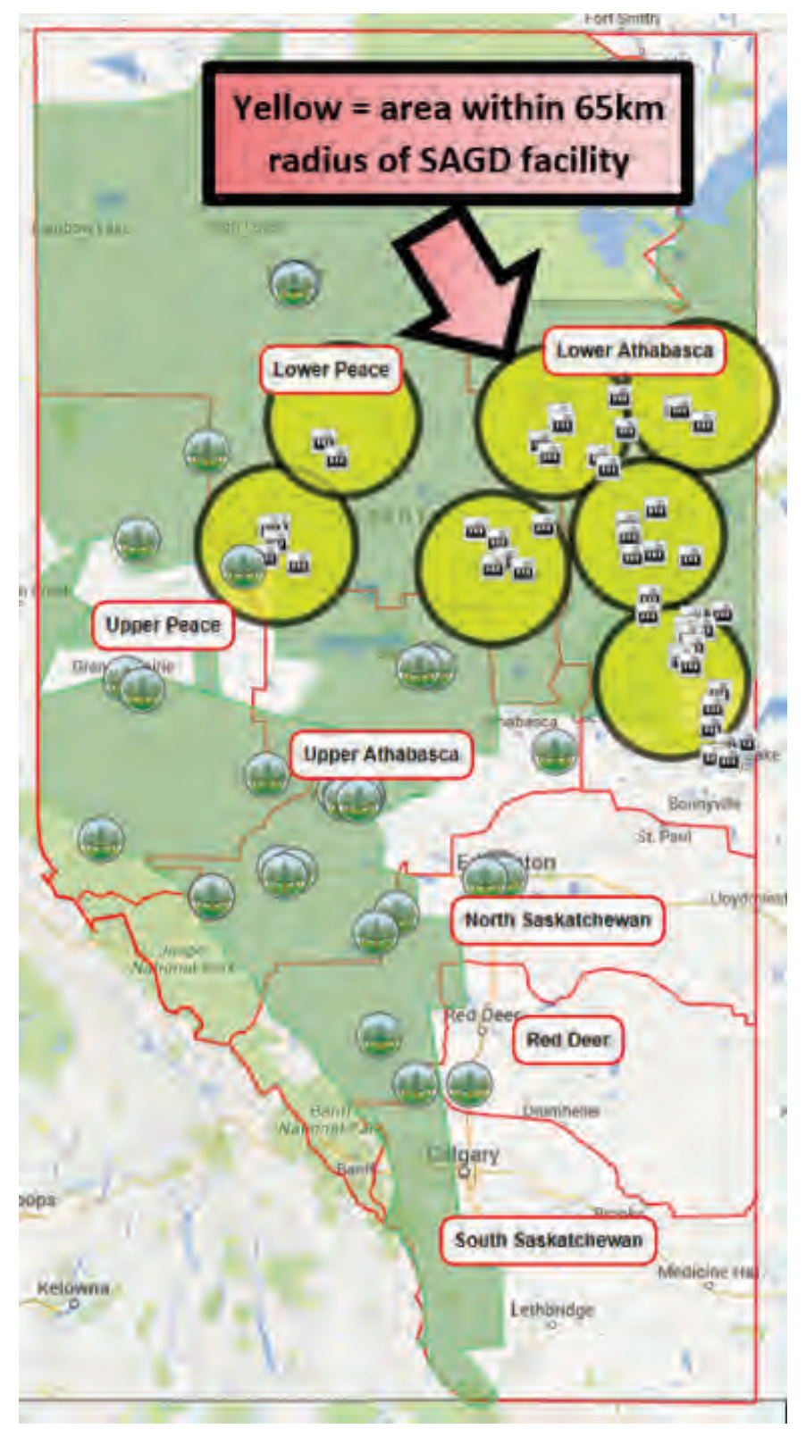


Fig. 2. Map of Alberta with 7 potential pyrolysis operations in the Lower Peace and Athabasca regions

Figures 3 shows an energy flow diagram for a typical 33,000 bbl/day SAGD facility [1,5]. Production of syngas, biooil and biochar is shown in orange [6].

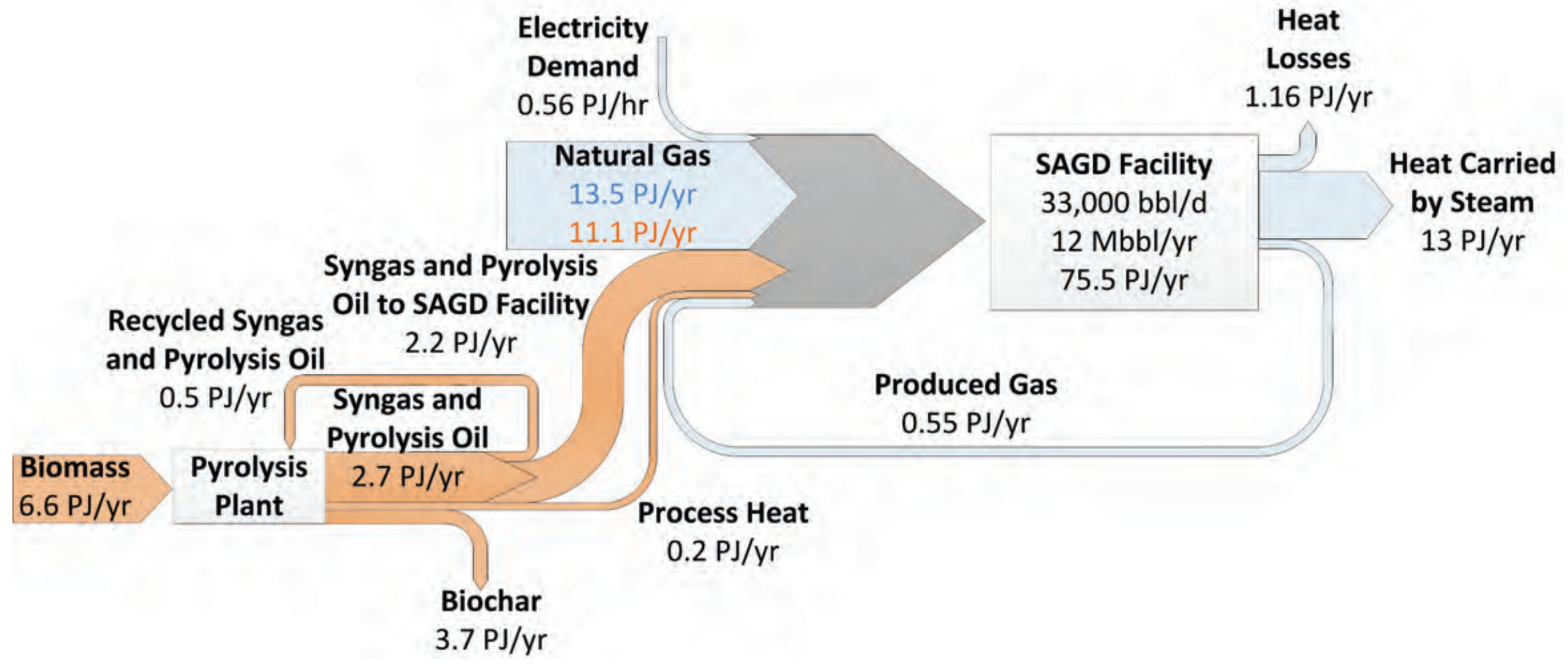


Fig. 3. Process flow for a 33,000 bbl/day SAGD Facility (BAU and Alternative)

RESULTS

REFERENCE

ALTERNATIVE

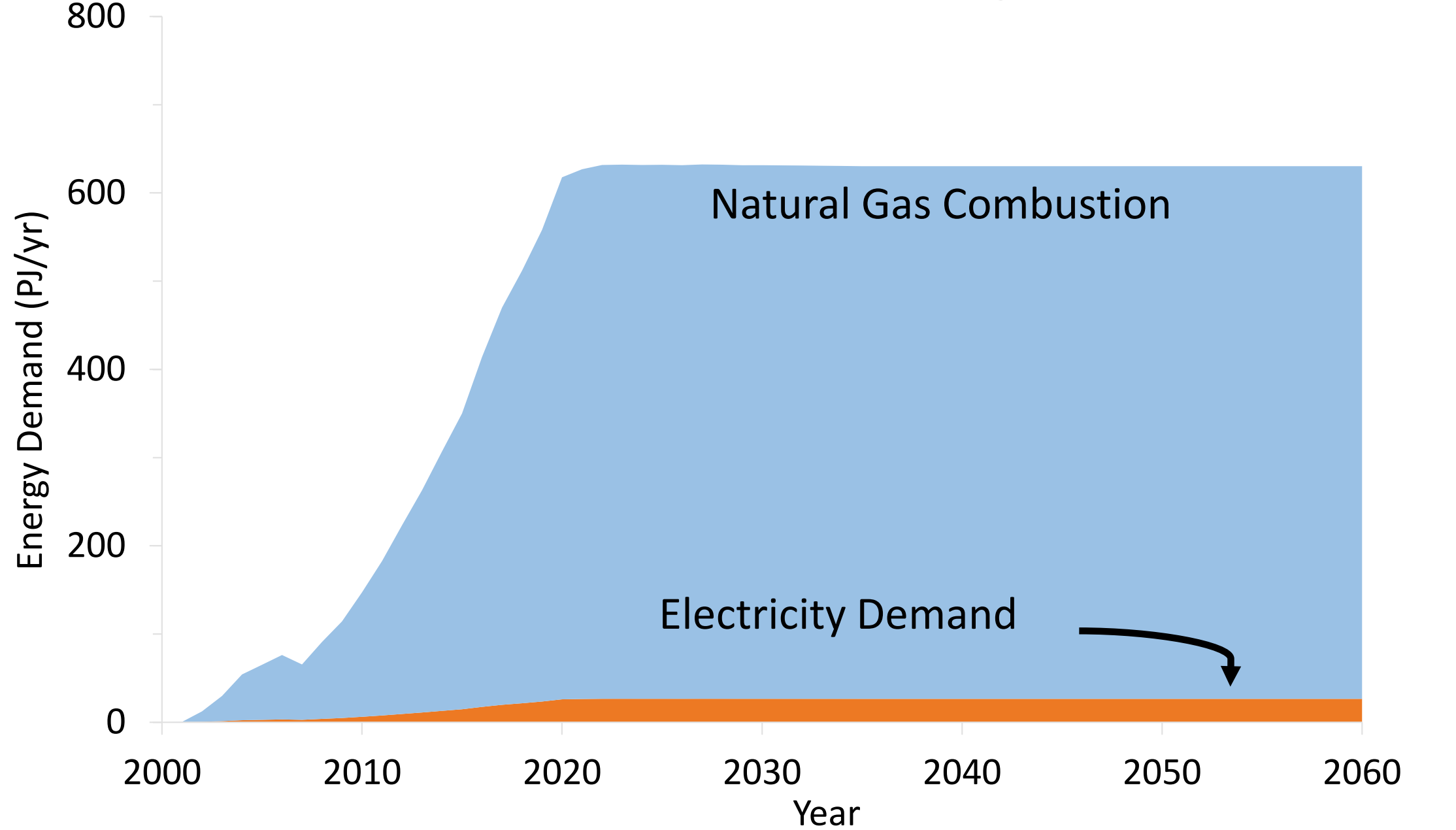
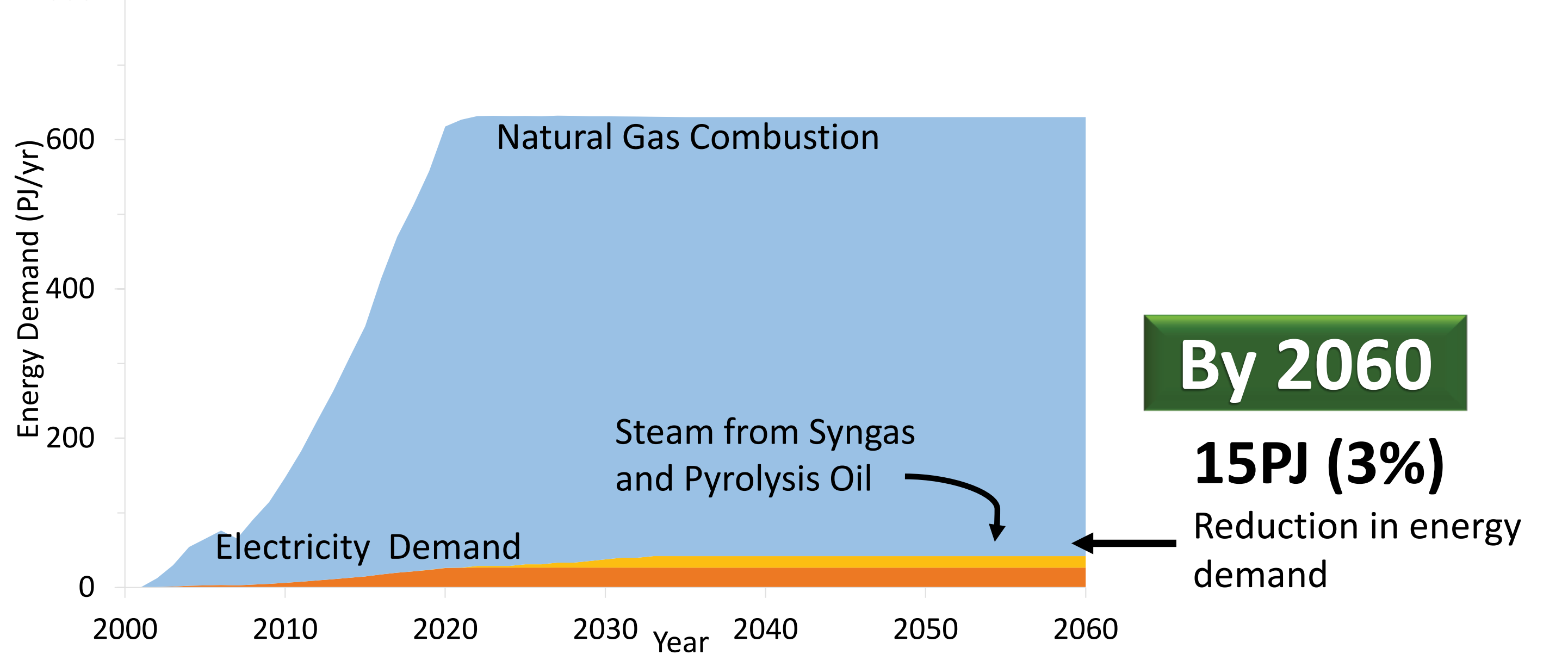


Fig. 4A. Projected SAGD steam and power demand in Alberta



By 2060

15PJ (3%)
Reduction in energy demand

Fig. 4B. Projected SAGD steam from NG and power demand in Alberta

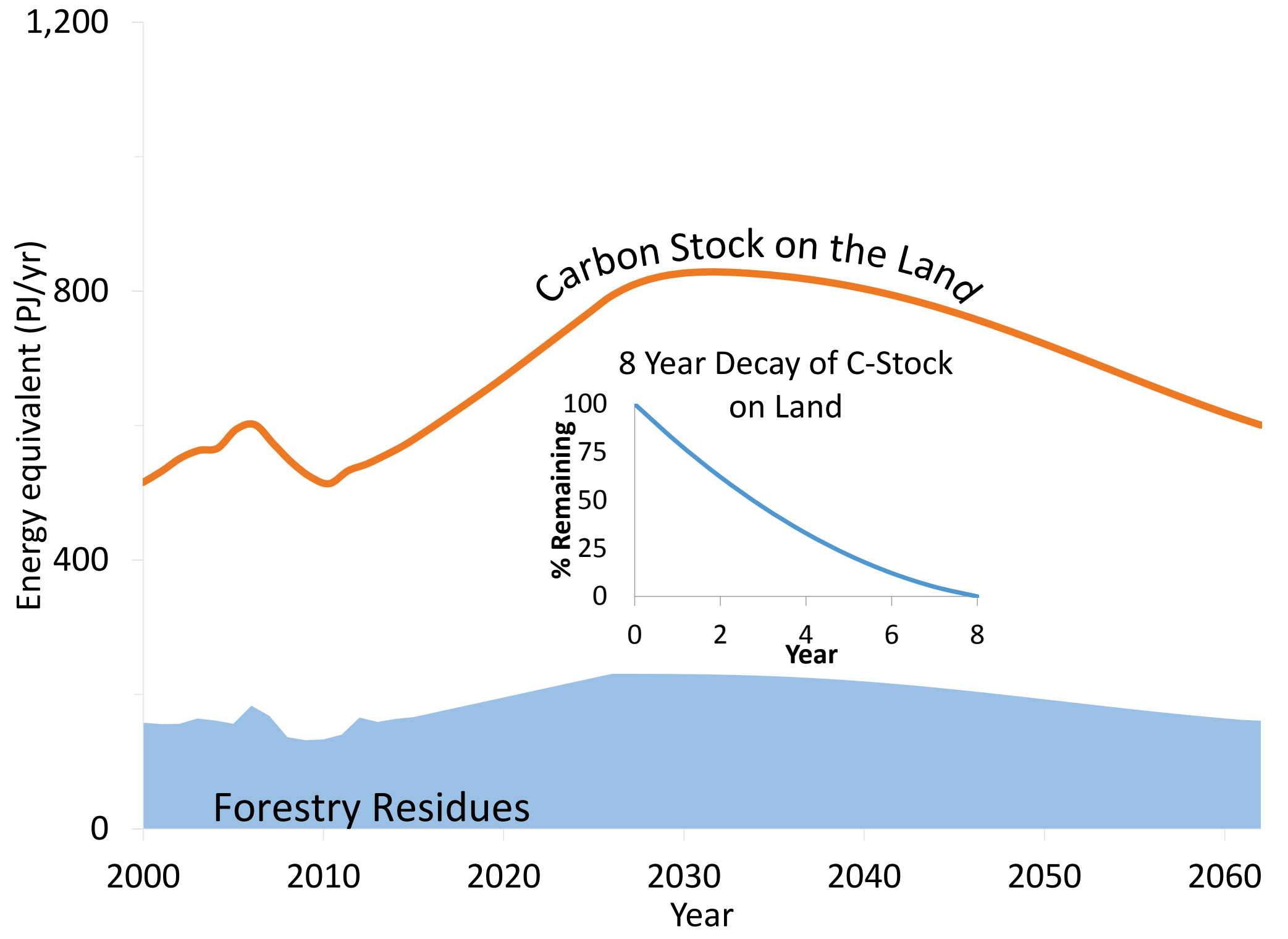
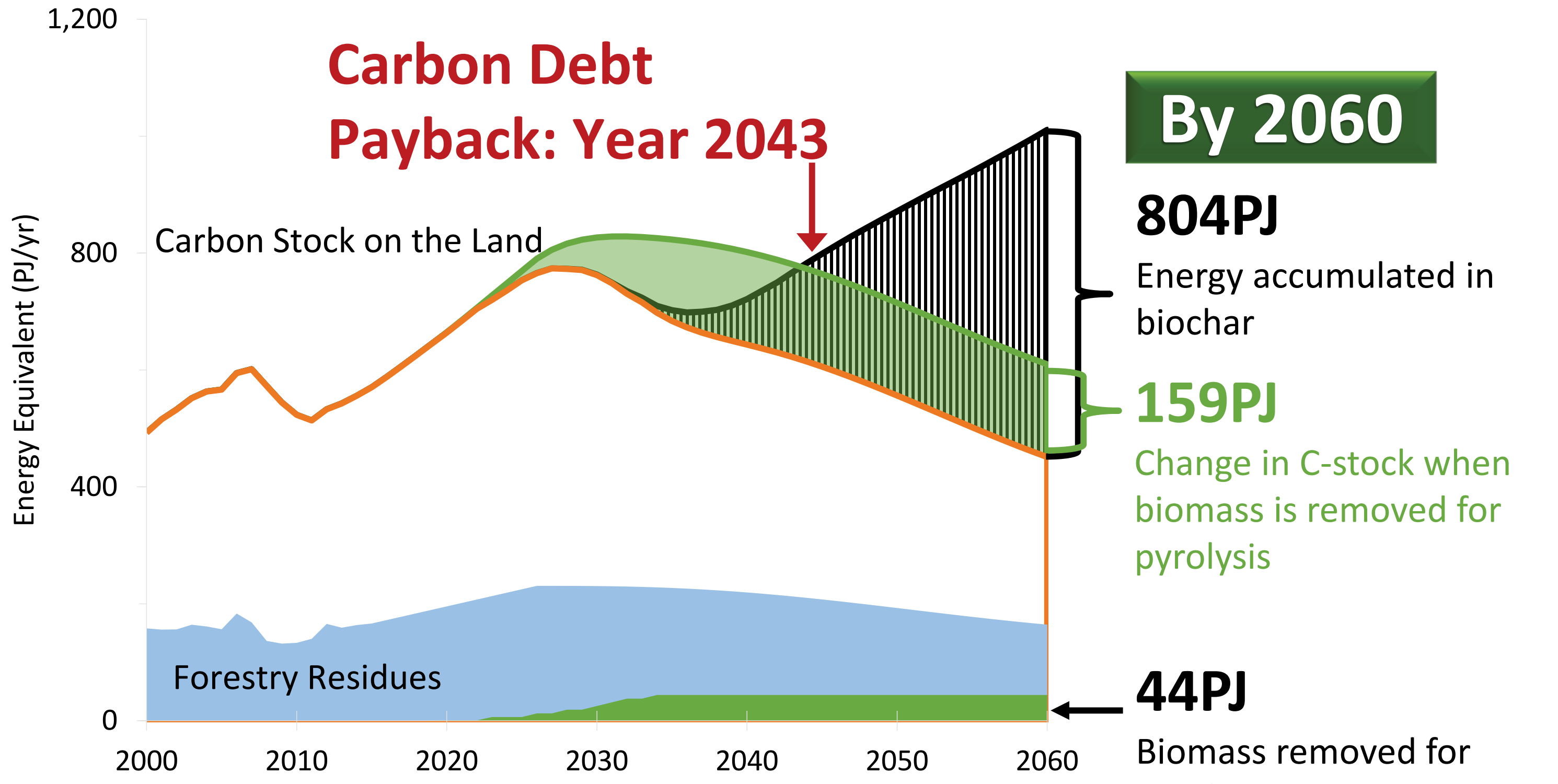


Fig. 5A. Carbon stock on land and forestry residues produced in Alberta



Carbon Debt Payback: Year 2043

By 2060

804PJ
Energy accumulated in biochar

159PJ
Change in C-stock when biomass is removed for pyrolysis

44PJ
Biomass removed for pyrolysis

Fig. 5B. Carbon stock on land and forestry residues produced in Alberta

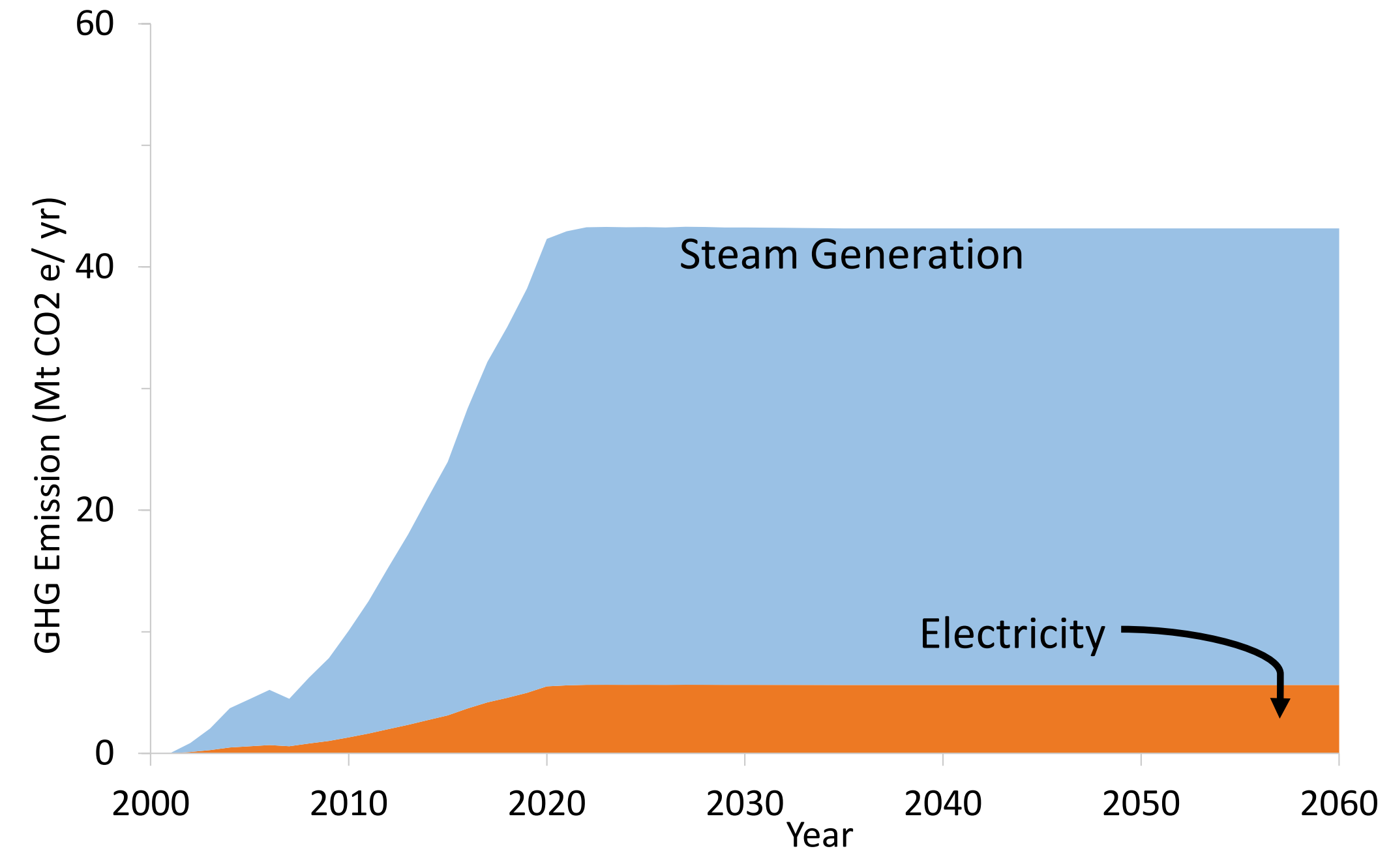
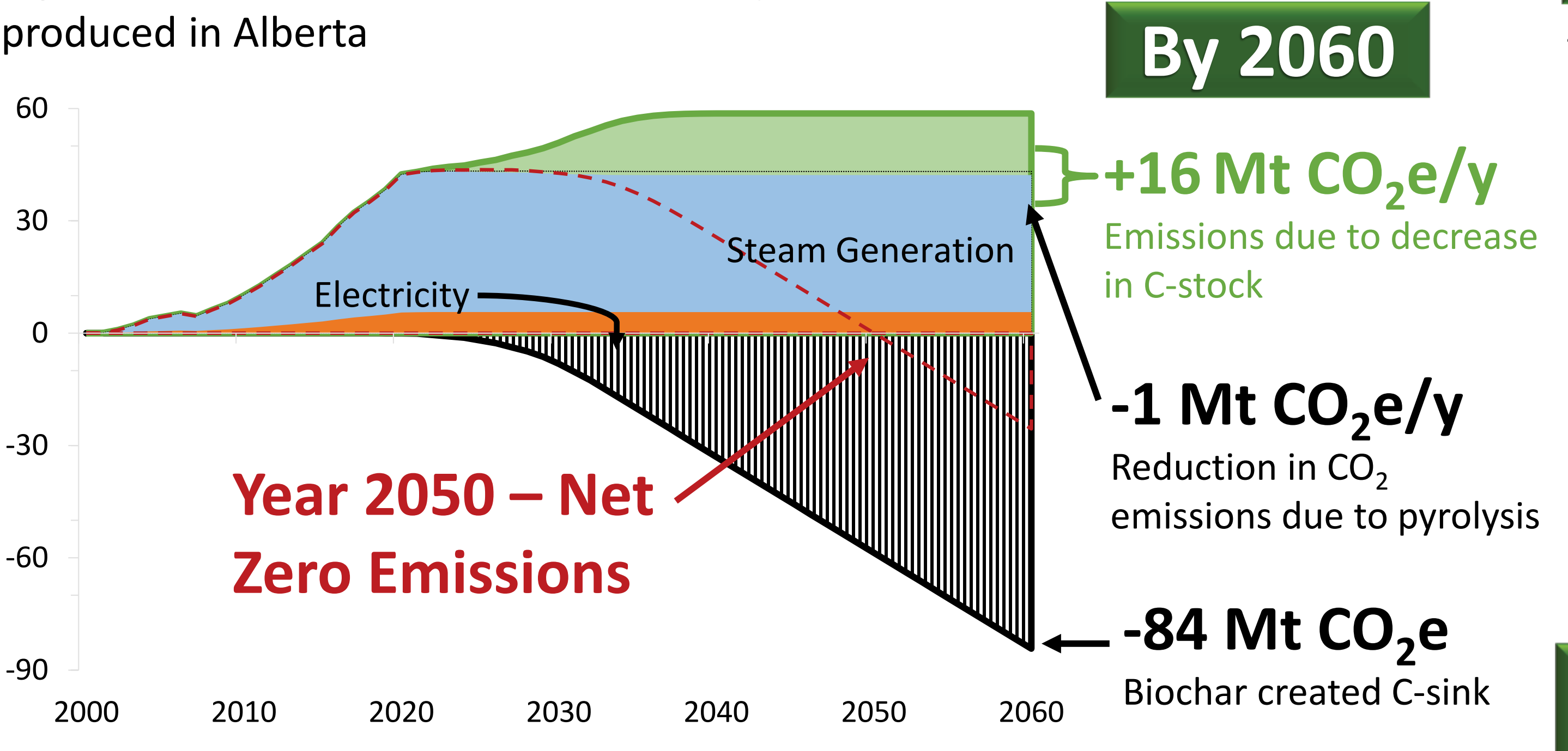


Fig. 6A. GHG emissions from generation of SAGD steam and power usage in Alberta



Year 2050 – Net Zero Emissions

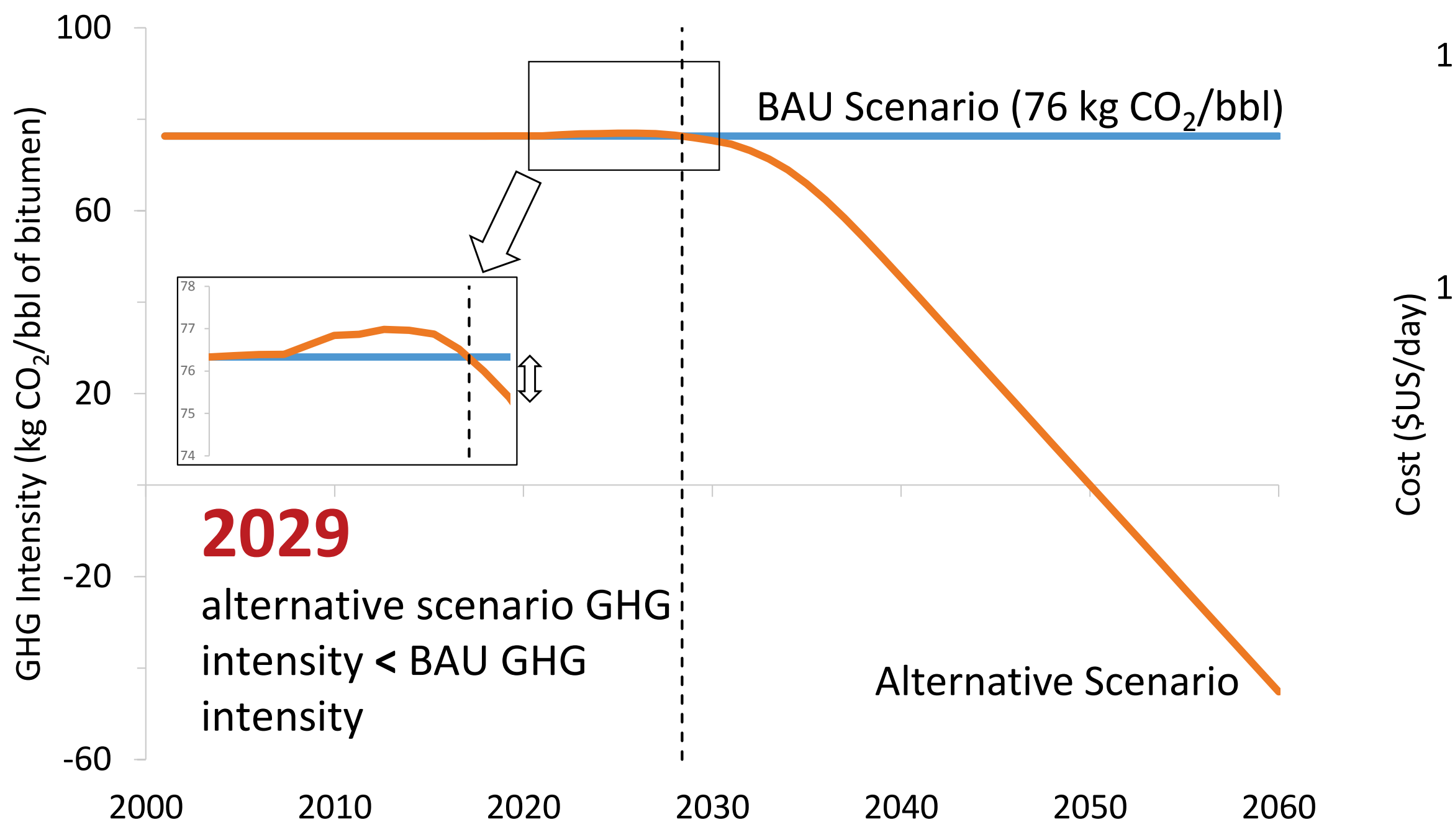
By 2060

+16 Mt CO_2e/y
Emissions due to decrease in C-stock

-1 Mt CO_2e/y
Reduction in CO_2 emissions due to pyrolysis

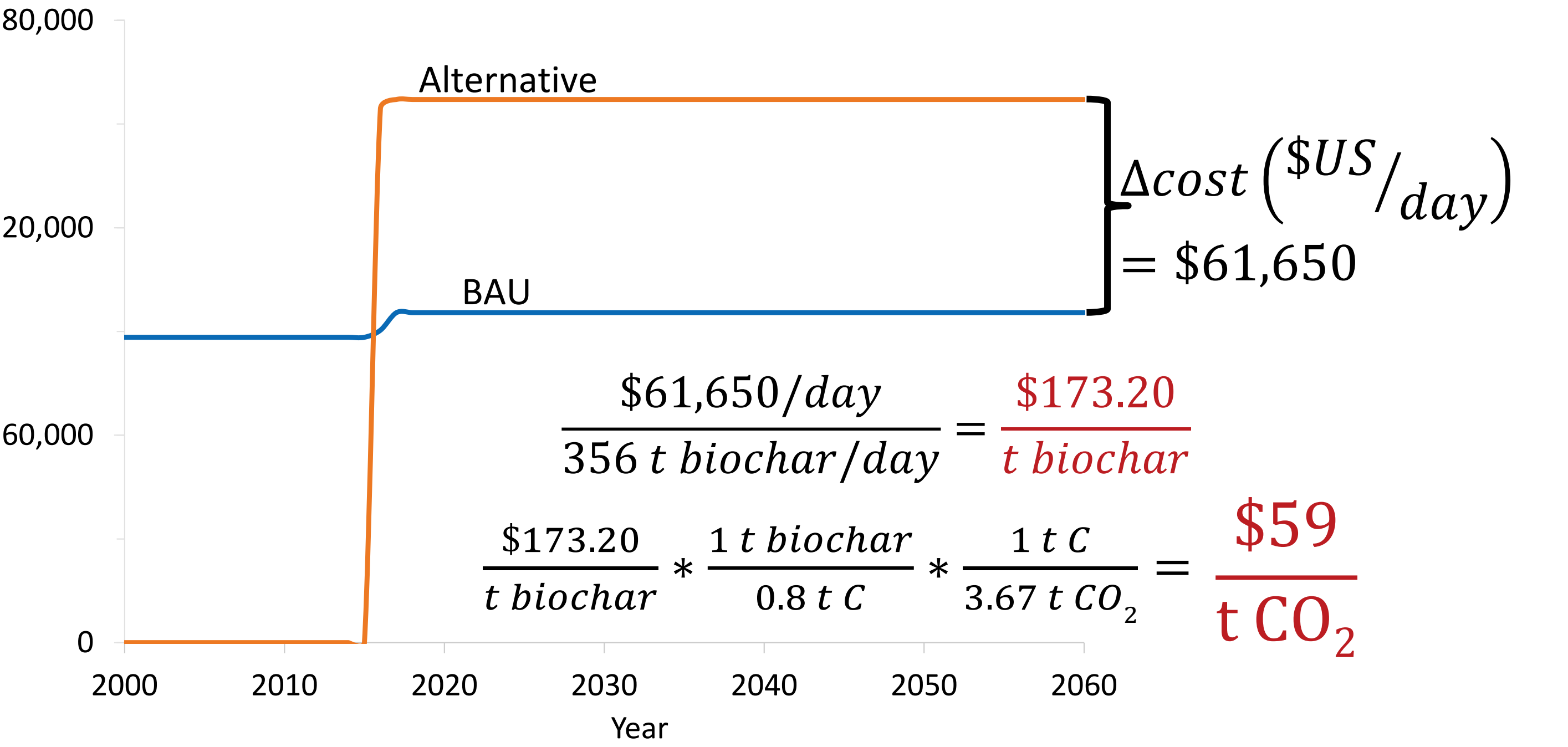
-84 Mt CO_2e
Biochar created C-sink

Fig. 6B. GHG emissions from generation of SAGD steam and power usage in Alberta



2029
alternative scenario GHG intensity < BAU GHG intensity

Fig. 7. GHG intensity of bitumen produced by SAGD in Alberta



$$\Delta cost\left({}^{\$US}/_{day}\right) = \$61{,}650$$

$$\frac{\$61{,}650/day}{356\ t\ biochar/day} = \frac{\$173.20}{t\ biochar}$$

$$\frac{\$173.20}{t\ biochar} * \frac{1\ t\ biochar}{0.8\ t\ C} * \frac{1\ t\ C}{3.67\ t\ CO_2} = \frac{\$59}{t\ CO_2}$$

Fig. 8. Operating costs for typical SAGD facility (BAU and Alternative)

DISCUSSION

The integration of biomass pyrolysis into SAGD facilities in Alberta is feasible for a maximum of 7 facilities at a capacity of 42t biomass/h. For each facility, the expected reduction in energy demand is 3% by 2060.

Forestry residues removed from the land for pyrolysis result in a significant reduction in carbon stock on land. This associates with lost energy (Fig 5B) and a temporary increase in emissions (Fig 6B). Biochar sequesters carbon for several 100 years and therefore in year 2043, the carbon stock on the land will paid off due to an accumulation in biochar (Fig 5B). In year 2050, SAGD operations will reach net zero emissions as shown on Fig. 6B.

Two scenarios exist for which the integration of pyrolysis is economical. This is to breakeven the transportation and operational costs.

1. Pyrolysis facilities are built and operated by a third party company. The produced biochar needs to be sold at $173.20
2. Pyrolysis facilities would be owned by the SAGD operators, given a carbon tax of $59/$tCO_2$.

Limitations in the analysis include:

- Sustainable harvest in forestry industry
- All biomass decay is aerobic and only produces CO_2 (no CH_4)
- Land use impacts of installing a pyrolysis facility
- Inefficiency of pyrolysis technology
- Effects of burning pyrolysis oil
- Changes in NO_x & SO_x from burning syngas and pyrolysis oil

CONCLUSIONS

The uptake of biomass pyrolysis in the SAGD energy system largely depends on the carbon tax policy, energy intensity of the system and technological advancement. Seven facilities are expected to be implemented by 2060, at a carbon tax of $59/$tCO_2$. Pyrolysis facilities more likely to be owned by SAGD operators as the carbon sequestration will remain with the oil companies. Lower CO_2 emissions through carbon sequestration, will improve the environmental report card for oil companies, and also enhance relations between Alberta's forestry and oil industries. Finally, a policy change to increase the carbon tax will incentivize the integration and uptake of biomass pyrolysis, and is recommended.

REFERENCES

[1] COSIA, *COSIA Challenge: Natural Gas Decarbonization,* 2014.
[2] D. Layzell and B. Straatman, "Pyrolysis Excel Data," September 2015. [Online]. Available: www.d2l.ucalgary.ca.
[3] K. G. Roberts, B. A. Gloy, S. Joseph, N. R. Scott and J. Lehmann, "Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change Potential," *Environmental Science and Technology,* vol. 44, no. 2, pp. 827-833, 2010.
[4] B. Burcu, "Pyrolysis: A Sustainable Way from Waste to Energy," [Online]. Available: http://www.oeaw.ac.at/forebiom/WS1lectures/SessionII_Uzun.pdf. [Accessed 25 Sept 2015].
[5] whatIf? Technologies Inc., 2014. Canadian Energy Systems Simulator (CanESS) - version 6, reference scenario. www.caness.ca
[6] D. A. Laird, R. C. Brown, J. E. Amonette and J. Lehmann, "Review of the pyrolysis platform for coproducing bio-oil and biochar," Biofuels Bioproducts and Biorefining, vol. 3, pp. 547-562, 2009.
[7] D. Bradley, "Canada- Sustainable Forest Biomass Supply Chains," Climate Change Solutions, Ottawa, 2007.
[8] InfoMine, "5 Year Natural Gas Prices and Price Charts," [Online]. Available: http://www.infomine.com/investment/metal-prices/natural-gas/5-year/.
[9] J. Markham, "Background Information," [Online]. Available: http://cse.ksu.edu/REU/S11/jmarkham/index_background_info.html.
[10] K. G. Roberts, B. A. Gloy, S. Joseph, N. R. Scott and J. Lehmann, "Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change Potential," Environmental Science and Technology, vol. 44, no. 2, pp. 827-833, 2010.

Important conversion factors: Volume of forestry residues = 50% of harvested volume [2]. Stable carbon in biochar = 80% of total biochar volume [7]. Total biochar produced = 35 wt% of biomass [6]. Biomass heating value = 19 GJ/BDt [2], carbon content = 50% [2], moisture content = 20% [2].

ACKNOWLEDGEMENTS

The authors would like to thank expert advisors, Mr. Rob Lavoie and Mr. Subodh Gupta for their invaluable insights, Dr. David B. Layzell and Dr. Bas Straatman for their mentorship and guidance and whatIf? Technologies, the owner of the CanESS model.

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Hydrothermal Liquefaction:

A Possible Solution To Alberta's Greenhouse Gas Emissions Crisis


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INTRODUCTION

Alberta's large freight transportation sector consumes 358 PJ/yr and emits 39 $MtCO_2e/yr$, primarily associated with the combustion of diesel fuel [3]. Making drop-in fuels from the 490 PJ/yr of residual biomass produced by Alberta's forestry and agricultural sectors provides one of the few low carbon alternatives for the freight transportation sector [3]. Hydrothermal liquefaction (HTL) of residual biomass is a promising technology that generates an energy rich bio-crude (40 MJ/kg) from residual biomass, which can either be used directly as a marine fuel or be refined to bio-based diesel [4]. This study generates scenario models for HTL production of Alberta's biomass resources to assess the impact on the diesel market in Alberta, the marine market in BC and the systems level greenhouse gas (GHG) emissions.

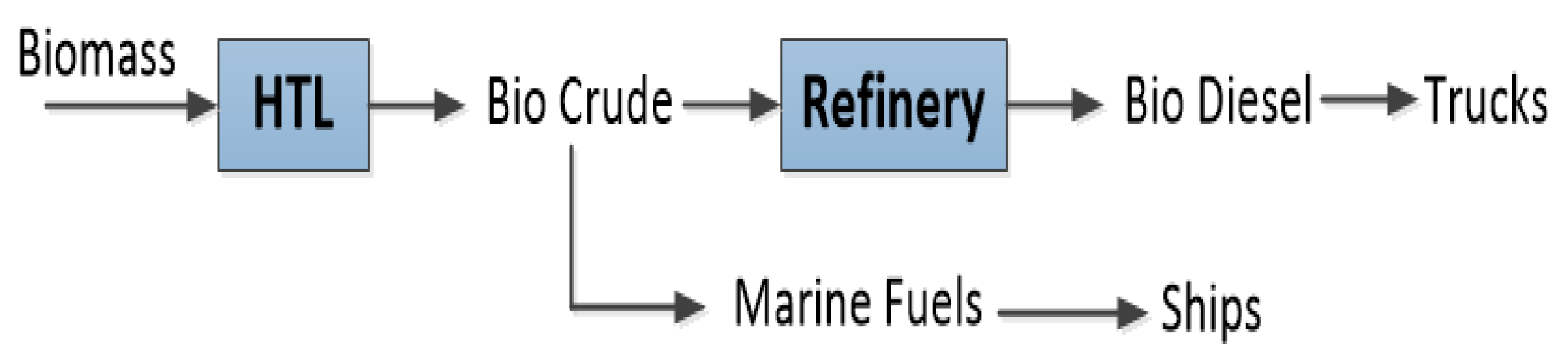


Fig 1. HTL Flow Diagram

METHODS

Assumptions for Scenarios:

- 8 years decay rate of trees
- 50% Carbon content in trees
- 0.4% forest harvested per year
- 50% of Agriculture land harvested per year
- 90% refinery efficiency
- Access to 80% of total forestry residual biomass and 100% of agricultural residual biomass
- Saturate 50% of BC marine bio-crude demand

Conversion factors were obtained from Steeper Energy [4] and whatIf Technologies [3].
Scenario models were created using Canadian Energy System Simulator (CanESS).

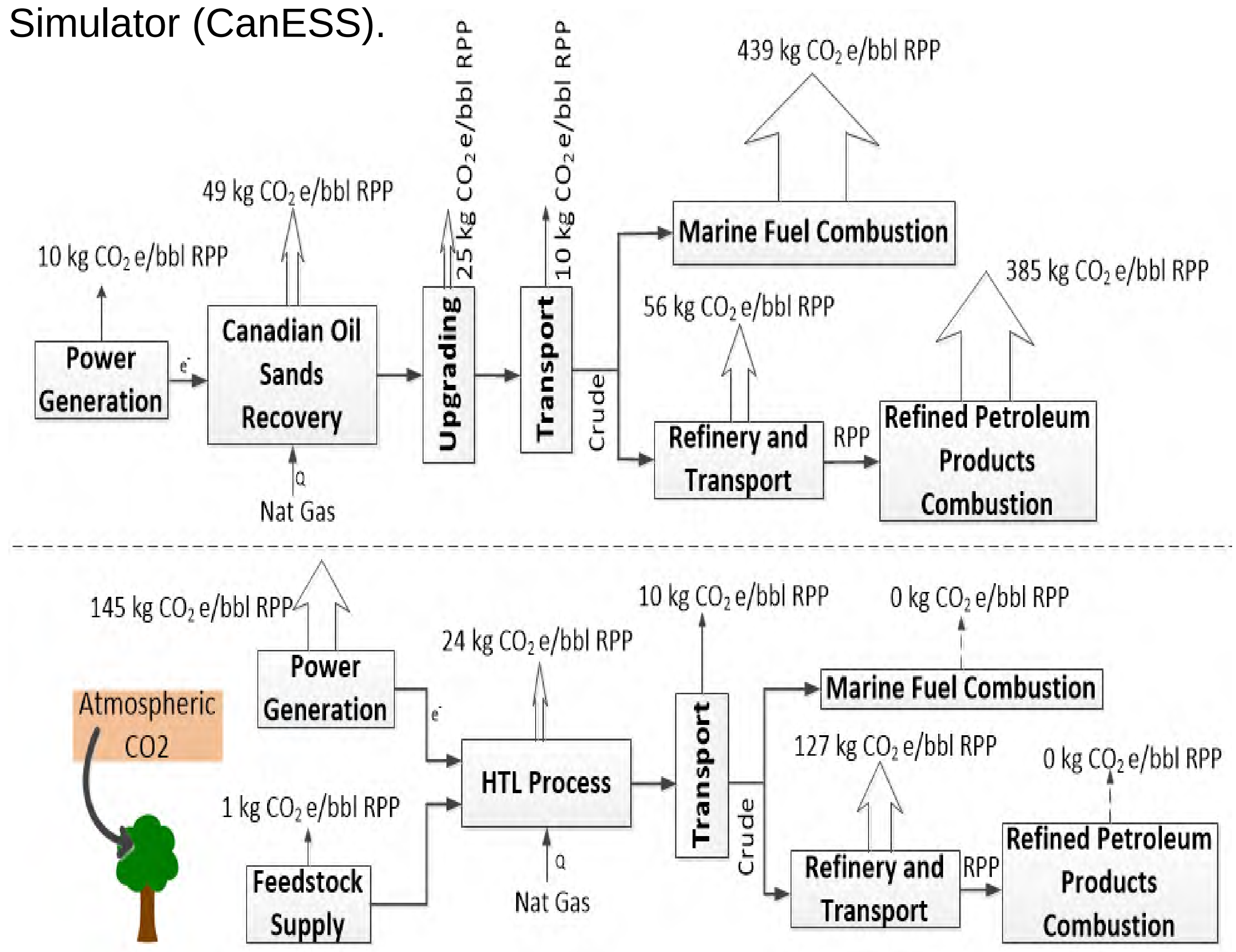


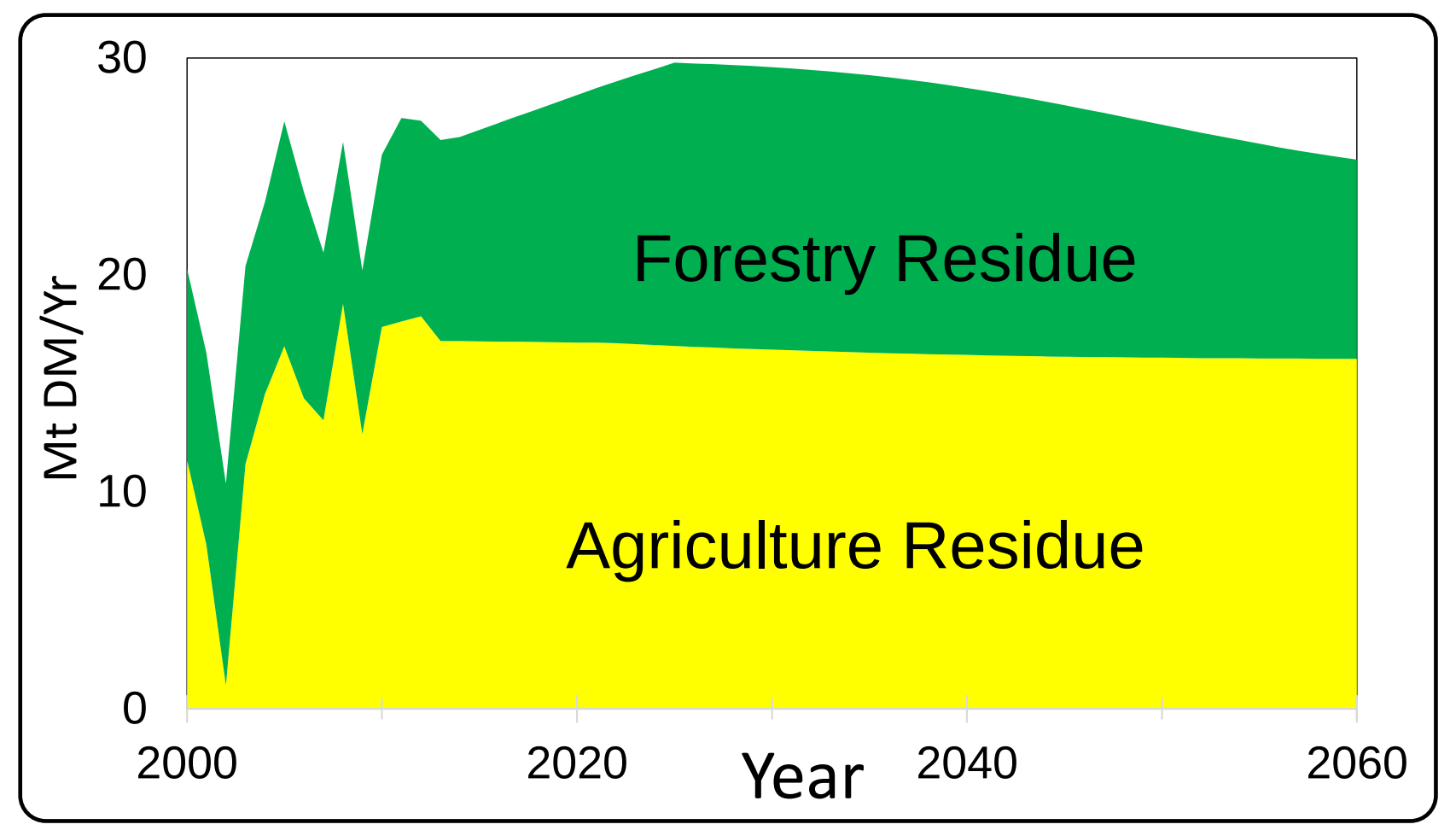
Fig 2. CO_2 Emissions from SAGD and HTL Processes

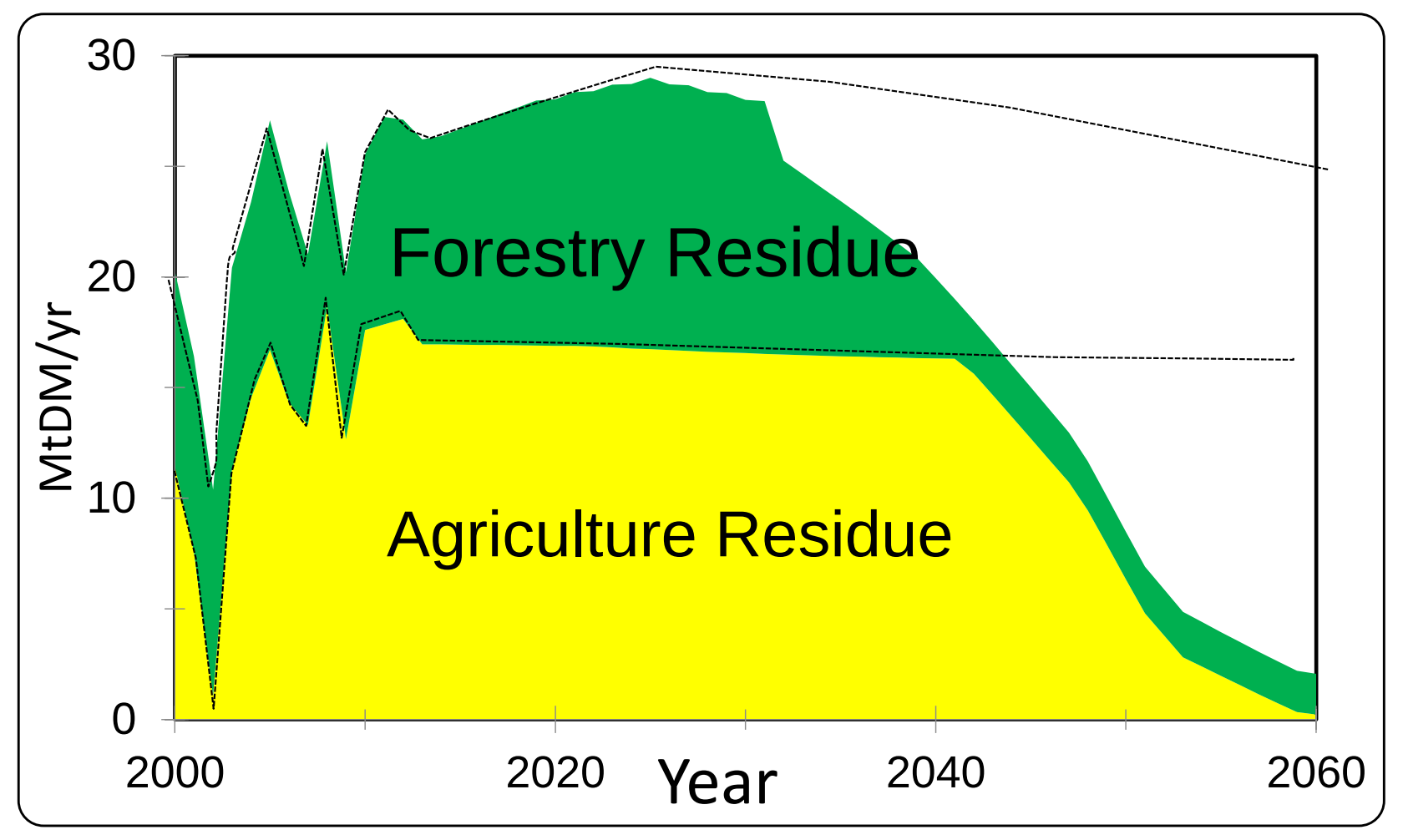
RESULTS

REFERENCE

ALTERNATIVE

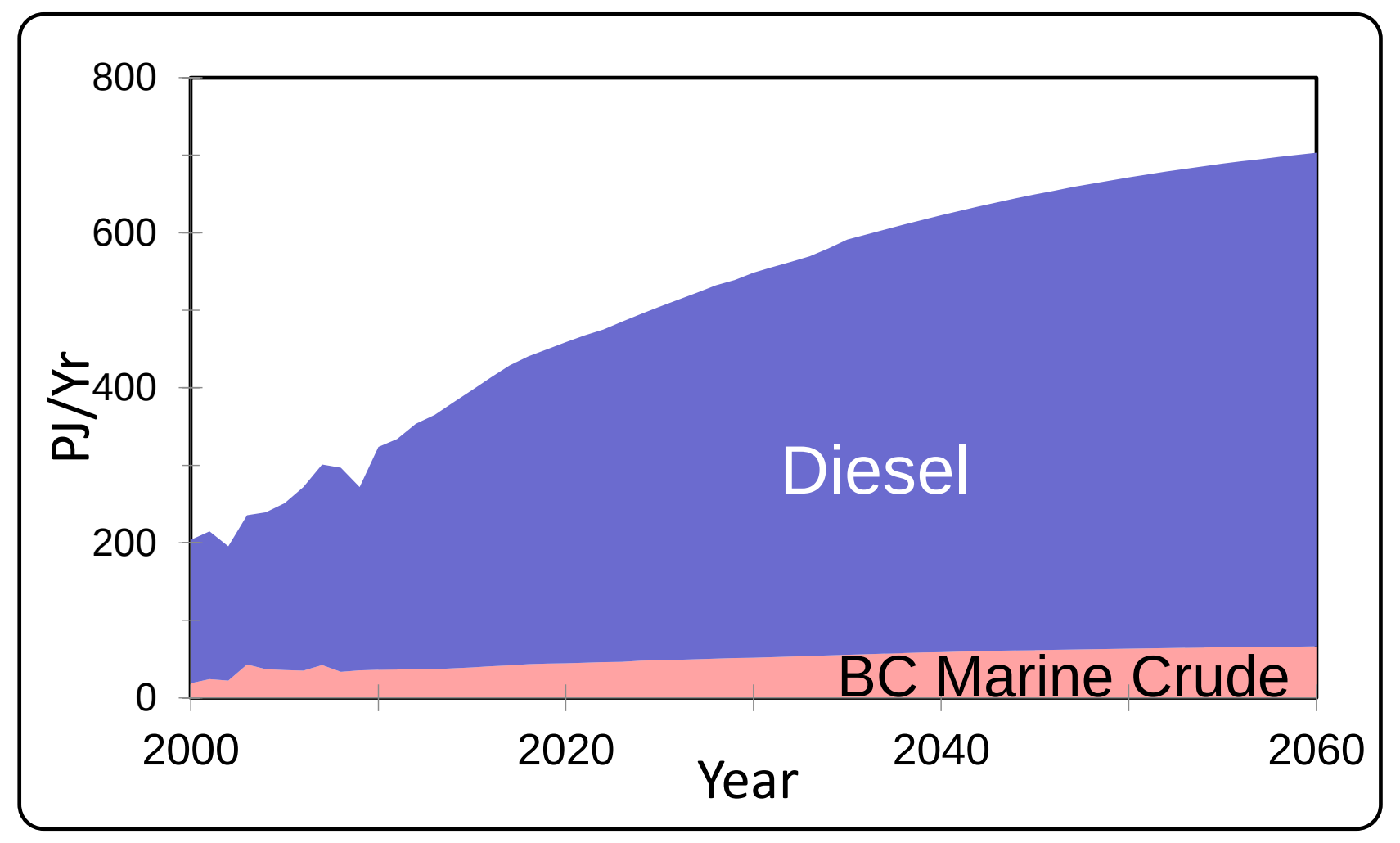
A. Amount of Residual Biomass in AB
Reference amount of biomass in AB compared with the amount of biomass after HTL implementation

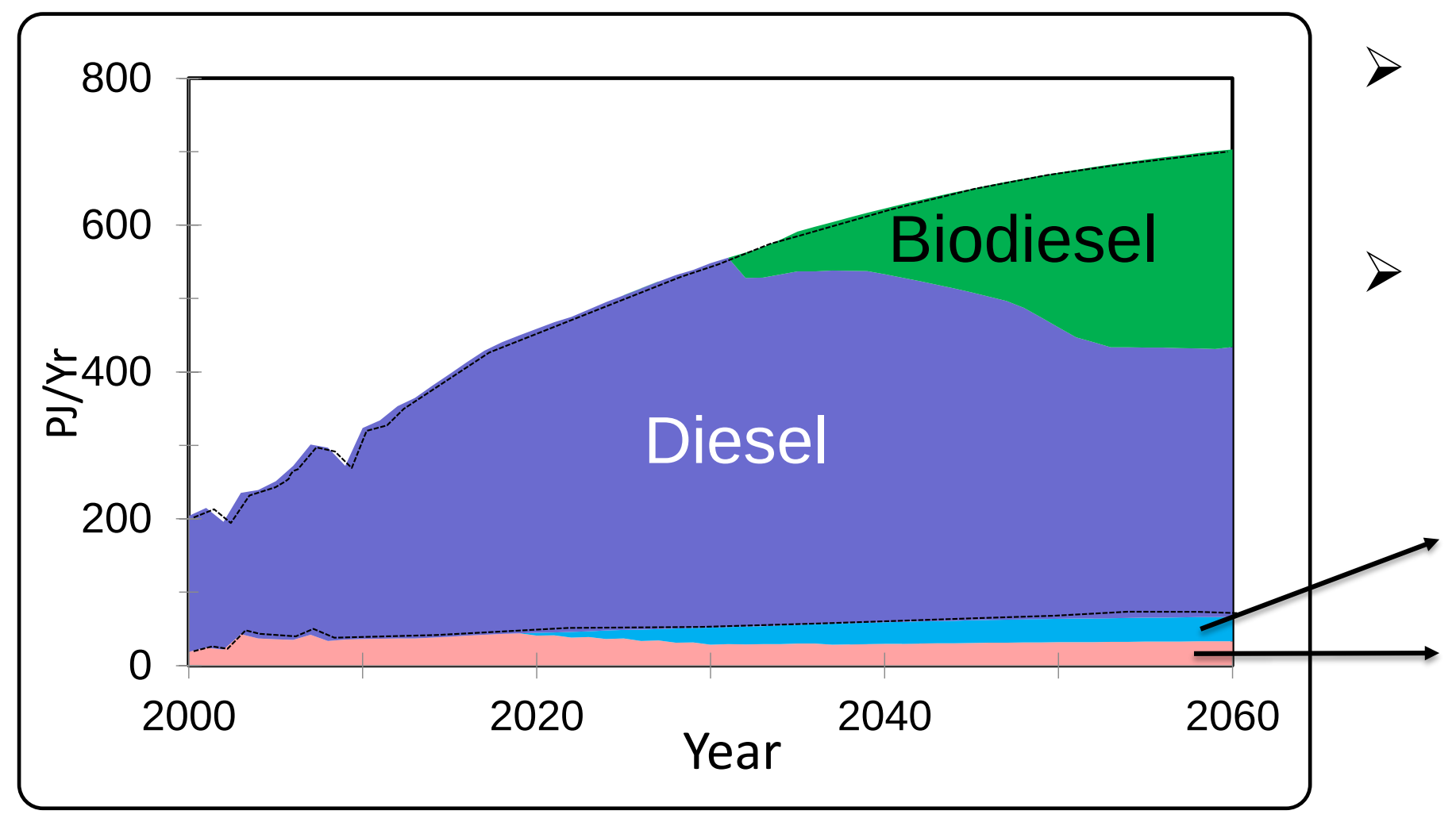




- 27-30 MtDM/yr of biomass is consumed by HTL in 2060 compared to the reference scenario

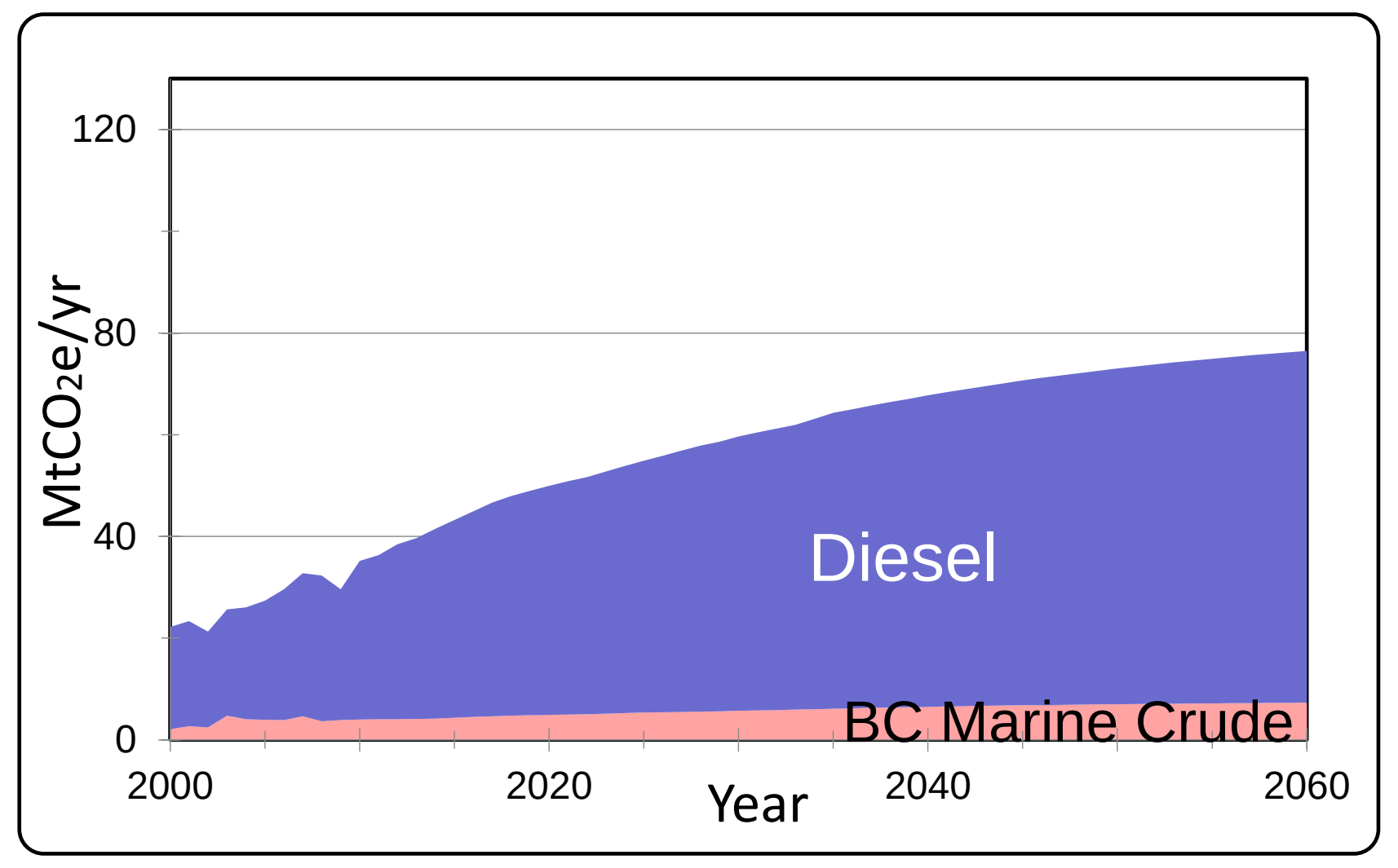
B. Freight Fuels Demand in AB and BC marine market
Comparing the reference scenario demand for diesel and BC marine Crude to the alternative demand after HTL implementation

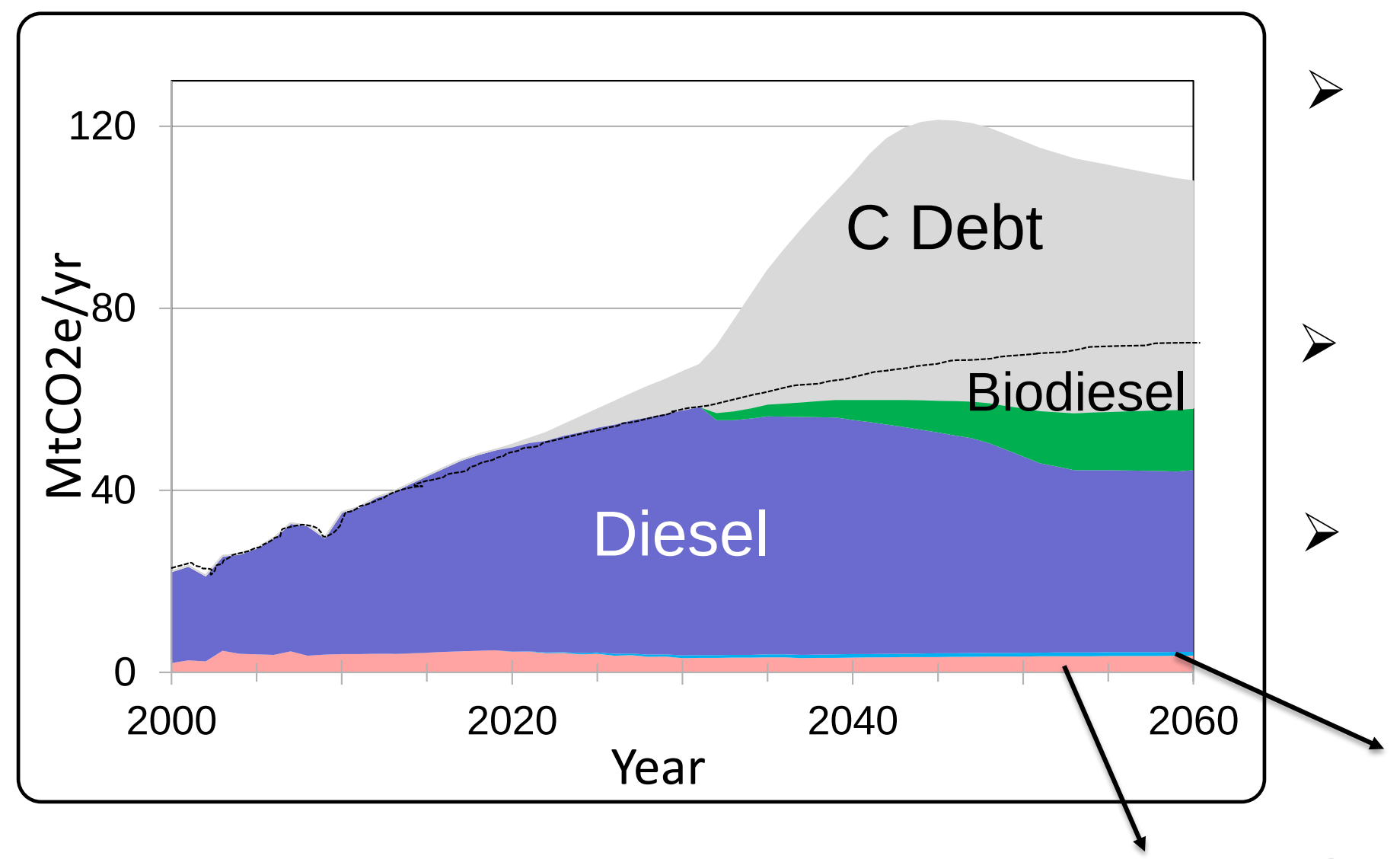




- 43% of diesel demand is met by HTL in 2060
- 50% of BC Marine Crude demand is met by HTL in 2060

C. Carbon Dioxide Emissions
Comparing reference CO_2 emissions from diesel and BC marine crude to the alternative CO_2 emission after implementing HTL technology in AB





- Additional 50 $MtCO_2e/yr$ is released by HTL from C-sink
- 43% reduction in CO_2 emissions from diesel by 2060
- HTL process releases 5.4 $MtCO_2e/yr$ by 2060

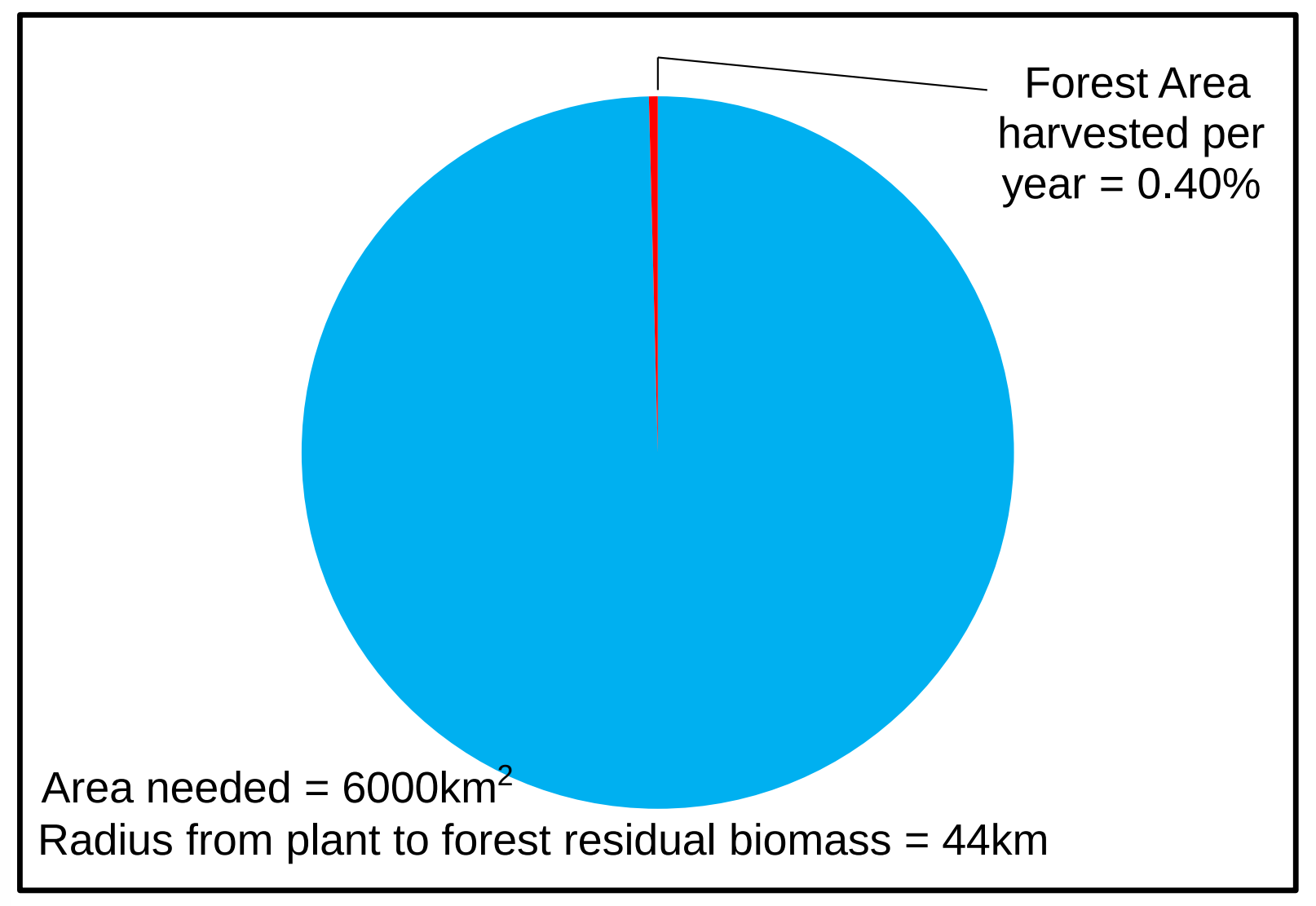


Fig 3 (a). Forest Area Needed for a Plant

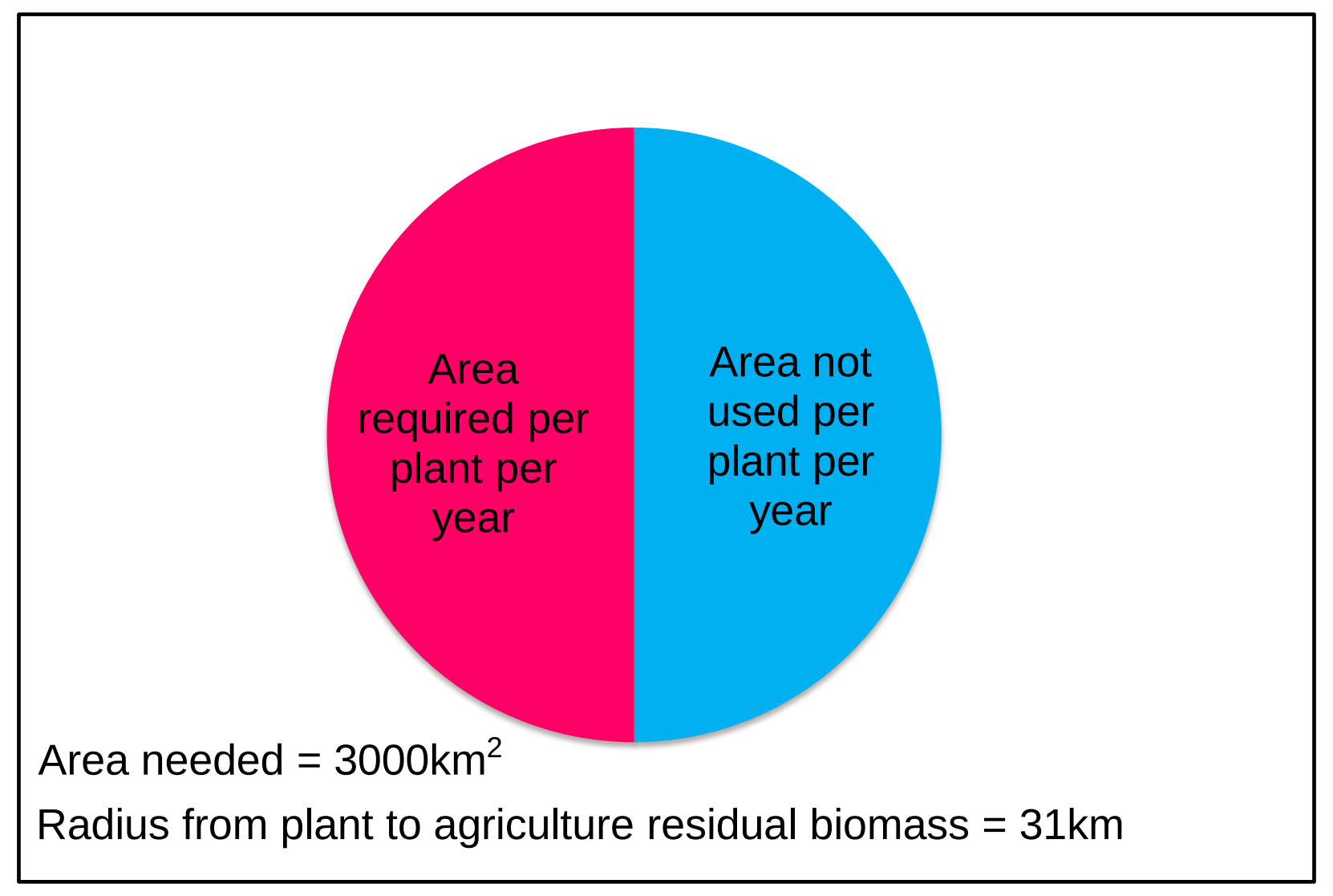


Fig 3 (b). Agriculture Area Needed for a Plant

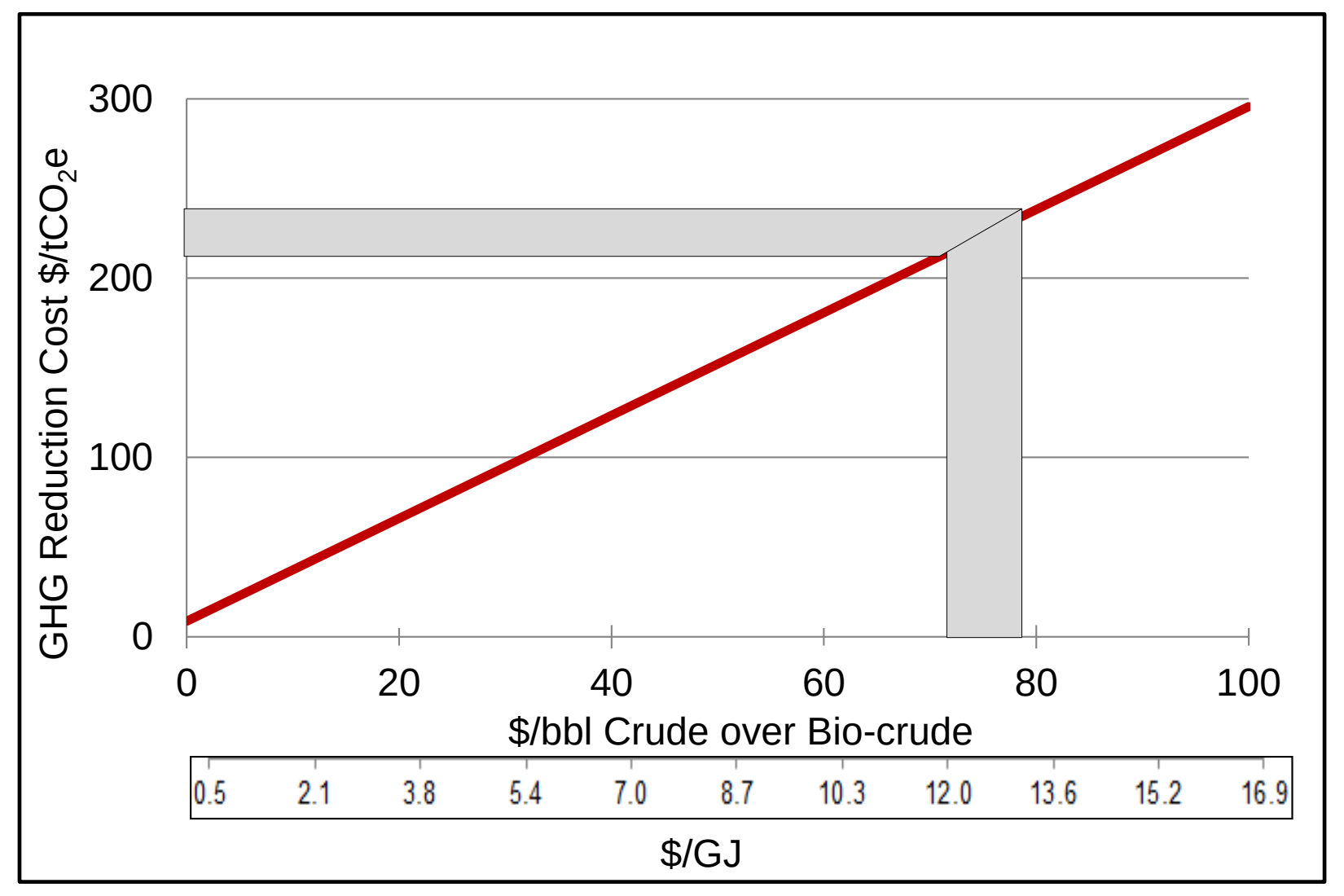


Fig. 4. Carbon tax needed to make HTL viable in AB

NOTE: Black dotted line represent reference scenario projections

REFERENCES

[1] IHS Energy, "Comparing GHG Intensity of the Oil Sands and The Average US Crude Oil," IHS Energy, 2014.

[2] Elliott, D. C., Biller, P., Ross, A. B., Schmidt, A. J., & Jones, S. B. (2015). Hydrothermal liquefaction of biomass: Developments from batch to continuous process. *Bioresource technology*, *178*, 147-156.

[3] whatIf? Technologies Inc., 2014. Canadian Energy Systems Simulator (CanESS) - version 6, reference scenario. www.caness.ca

[4] Steeper Energy The Renewable Oil Company, [Online].Available: http://steeperenergy.com/.

[5]GHG Emissions. (2015). Retrieved December 1, 2015, from http://www.oilsandstoday.ca/topics/ghgemissions/Pages/default.aspx

[6]Lattanzio, R. K. (2012, May). Canadian oil sands: Life-cycle assessments of greenhouse gas emissions. Congressional Research Service, Library of Congress

DISCUSSION

From our projections, HTL technology was able to capture 43% (254PJ/yr) of the total diesel demand and 50% (33PJ/yr) of the total marine fuel demand in BC by 2060. This led to a 43% (31$MtCO_2e/yr$) reduction of CO_2 emissions from SAGD in 2060. However an additional 50$MtCO_2e/yr$ was released from HTL. This increase in CO_2 emission was solely due to the utilization of carbon sinks (in this case forestry biomass) as fuel for HTL and not from the HTL process itself as the process is very efficient (about 77% efficiency)[4]. This creates a Carbon debt on land. In a sense, this is the penalty we pay for using forestry biomass.

HTL is a fairly new technology and as a result the cost is fairly high with an O&M cost of about $40 million/yr [4].

In order to make this technology viable and competitive at the current price of crude ($44-$50/bbl), price on carbon emissions will need to be about $230/$tCO_2e$.

CONCLUSIONS

HTL technology has the potential to reduce CO_2 emissions from SAGD by about 43% (31$MtCO_2e/yr$) by 2060. That said, the cost of the technology and the utilization of carbon sinks through the use of forestry biomass leads to a carbon debt that poses a serious threat to this technology as this releases additional 50$MtCO_2e/yr$. To tackle this issue of Carbon debt we recommend the following policies:

- Improvement in the efficiency of HTL process. As quite a bit of CO_2 is released from refining bio-crude and from the electricity needed to run the HTL process
- More research and development on HTL technology as it is a fairly new technology
- Better and sustainable forest management practices have to be implemented if this technology is to be pursued
- Lastly, we recommend focusing on the BC Marine market as CO_2 saved (127kg/bbl) from not refining bio-crude can help reduce the carbon debt we pay. However, this is limited by the size of BC marine market

In order to make this technology feasible and competitive in the current AB market they have to be a price on CO_2 emissions of about $230/$tCO_2e$

ACKNOWLEDGEMENTS

We would like to acknowledge What if technologies, CanESS, and steeper energy for their support. We would also like to acknowledge Dr.Layzell and Dr.Straatman for their support and assistance during the course of this project.

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Replacing Alberta's Transportation Fuel with Home Grown Biofuel

Can Alberta Crop Residuals Supplement Fuel Demand and Reduce GHG Emissions?


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INTRODUCTION

Freight transportation in Alberta consumed 286 PJ in 2014 contributing over 25 Mt of GHG to the atmosphere – nearly 10% of the provinces GHG emissions.

This project looks at a Thermochemical Gasification process which uses Fischer-Tropsch synthesis to convert lignocellolosics to diesel and other hydrocarbons and its potential to reduce GHG emissions [1].

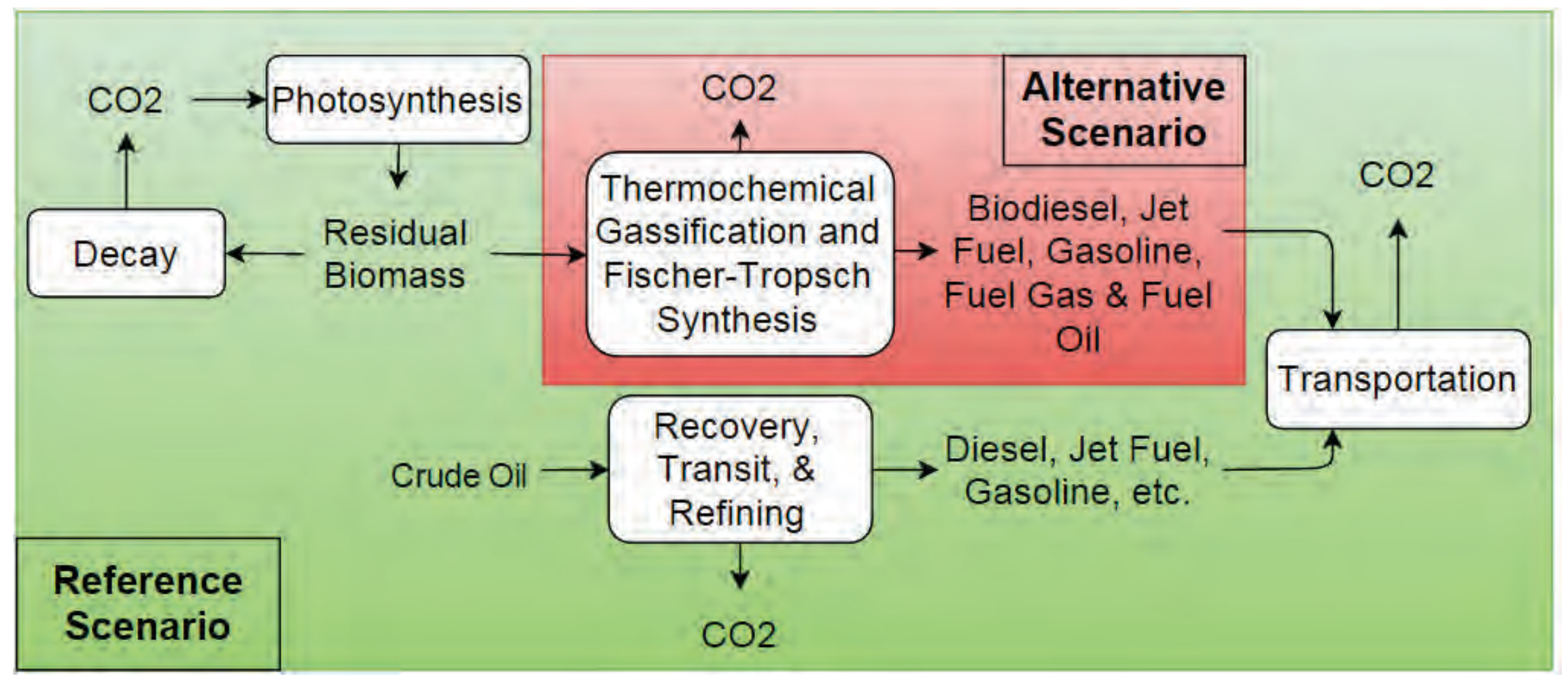

Fig. 1 CO_2 Flow Chart for Reference and Alternative Scenarios

METHODS

Our reference scenario and Alberta crop projection data were provided by Dr. Layzell from the CanESS model (CESAR).

The alternative scenario process was taken from the Thesis of Maria Pinilla (Fig. 2) [1], which is assumed to be accurate.

Assumptions

- Alternative process has 67% efficiency
- Current freight systems can transport 1.15 Mt of biomass / facility / year
- Stable biomass prices at $115/tonne [2]
- First facility in 2025, new facility every 3 years, each with 15 PJ annual capacity

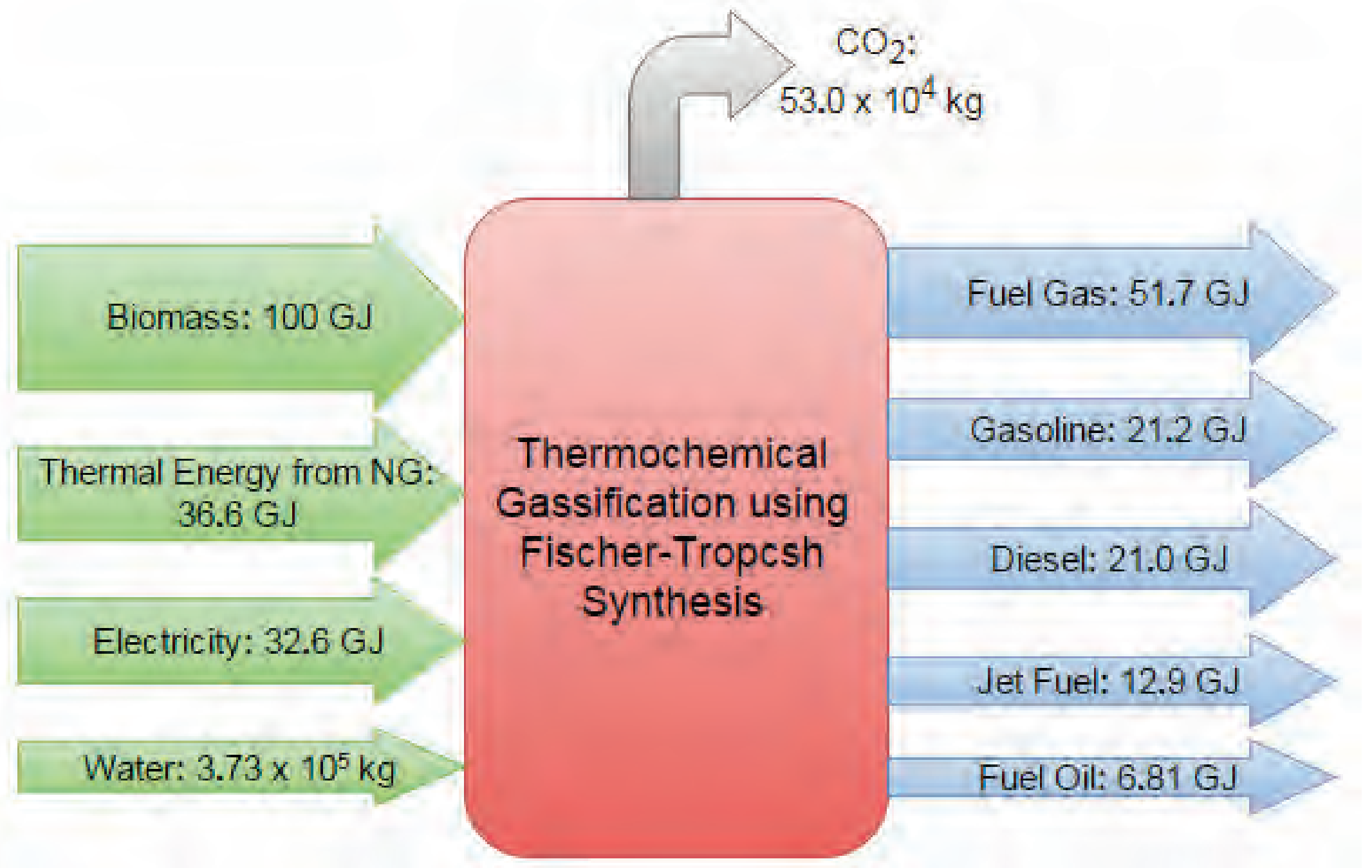

Fig. 2 Alternative Scenario Process Flow Chart [1]

RESULTS & DISCUSSION

REFERENCE

ALTERNATIVE

NOTES:

Residual Biomass

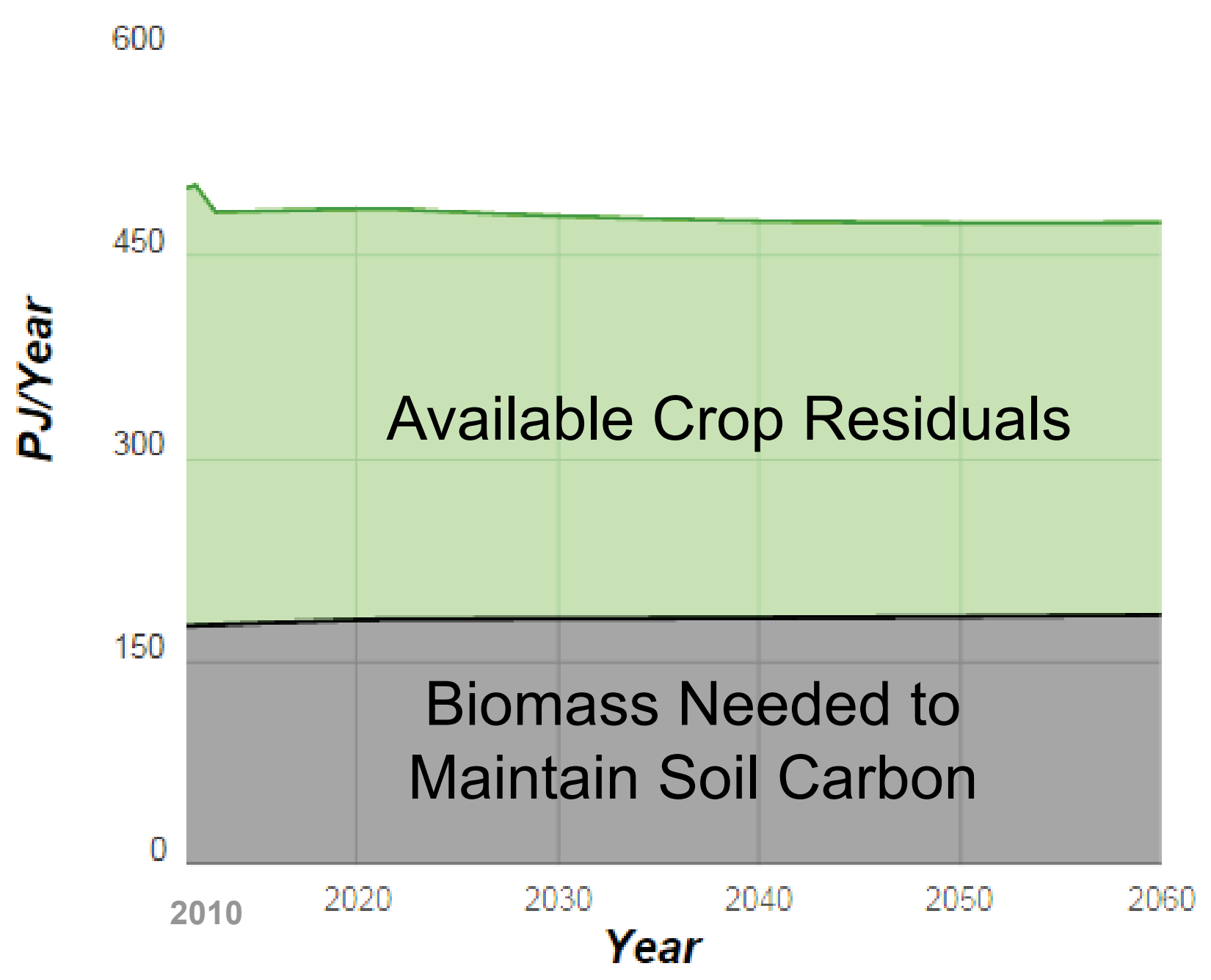

Fig. 3a Ref Residual Biomass

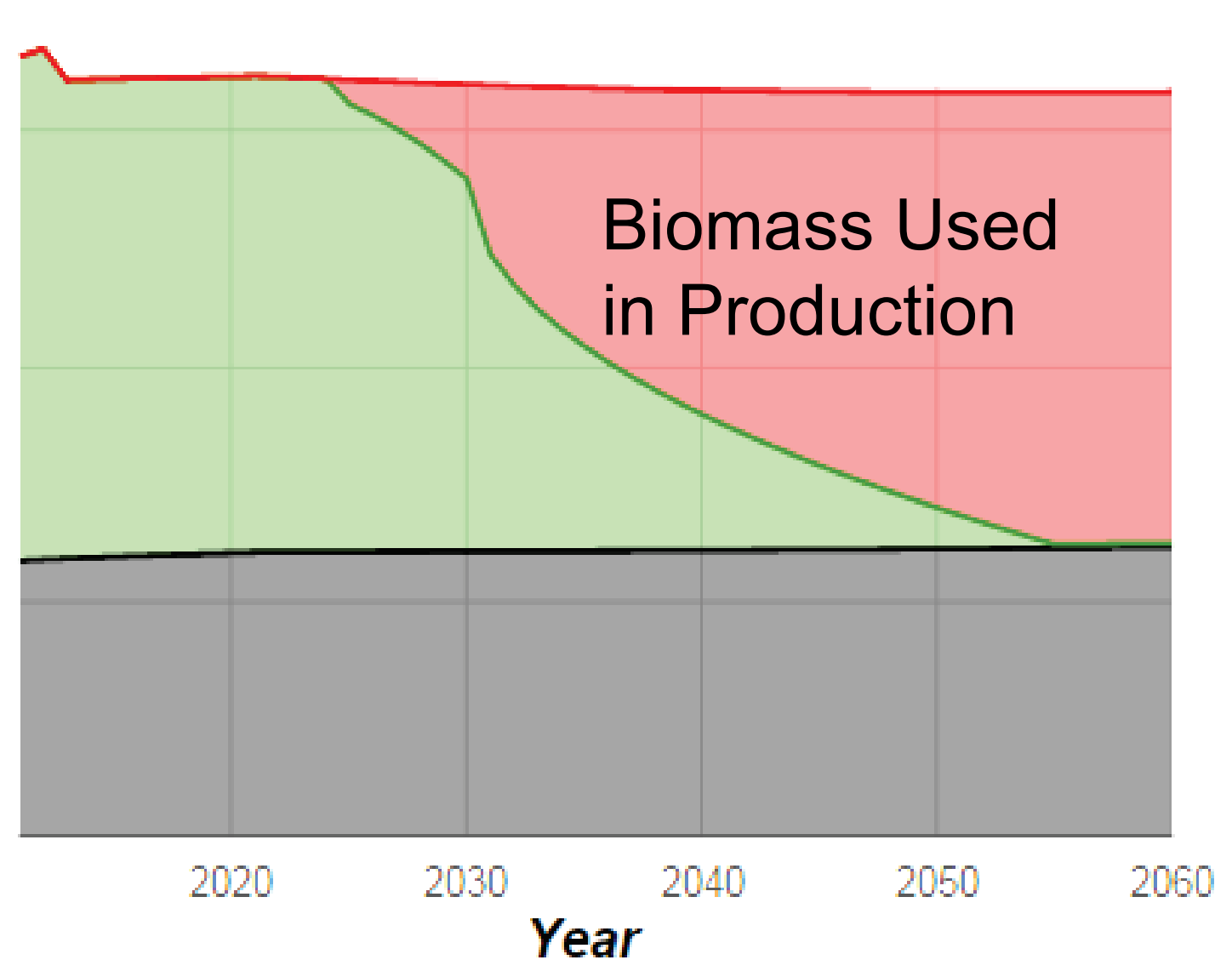

Fig. 3b Alt Residual Biomass

Peak residual biomass use by 2054, roughly 290 PJ per year.

By maintaining soil carbon, GHG mitigation is maximized.

Transportation Fuel Demand

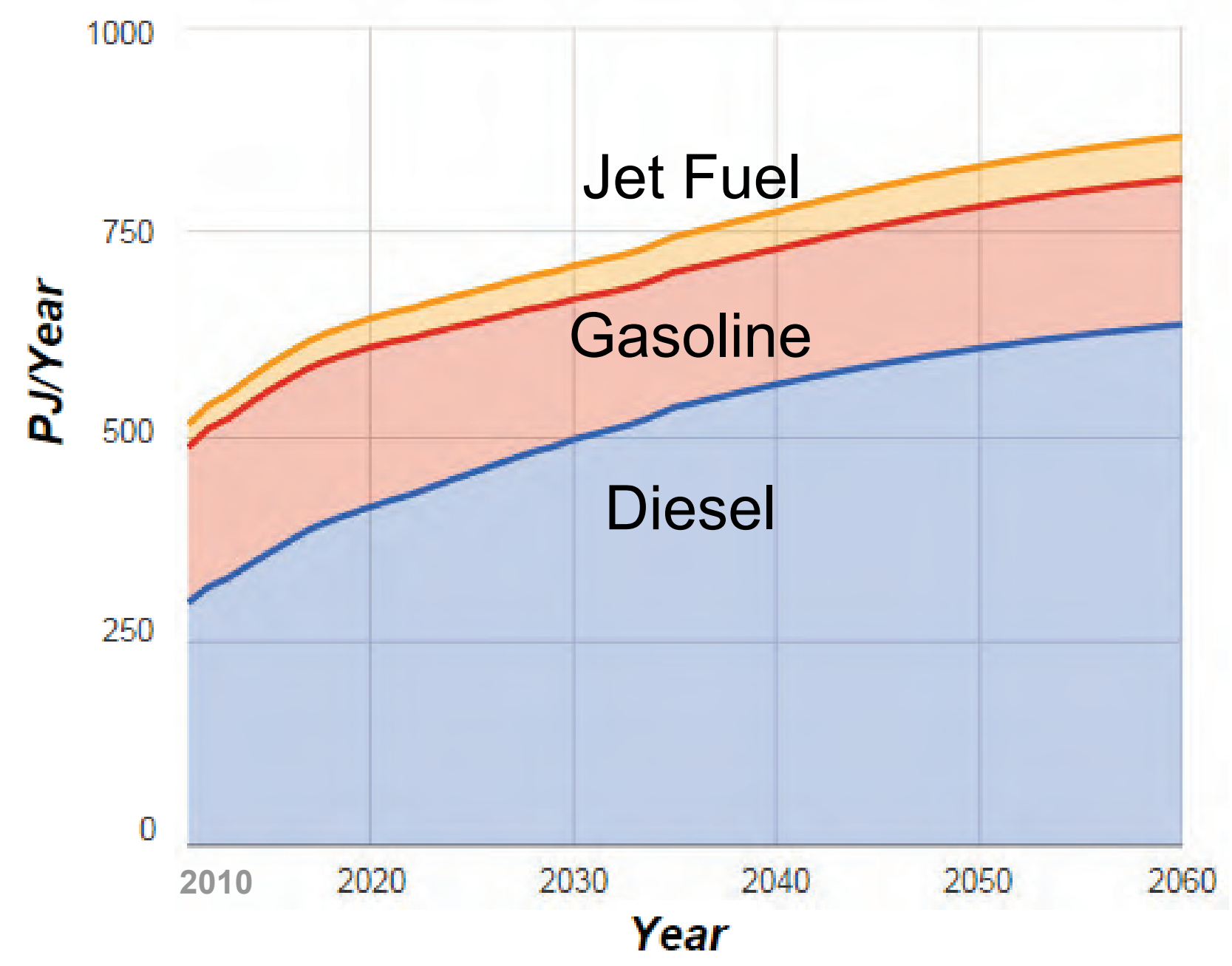

Fig. 4a Ref Fuel Production

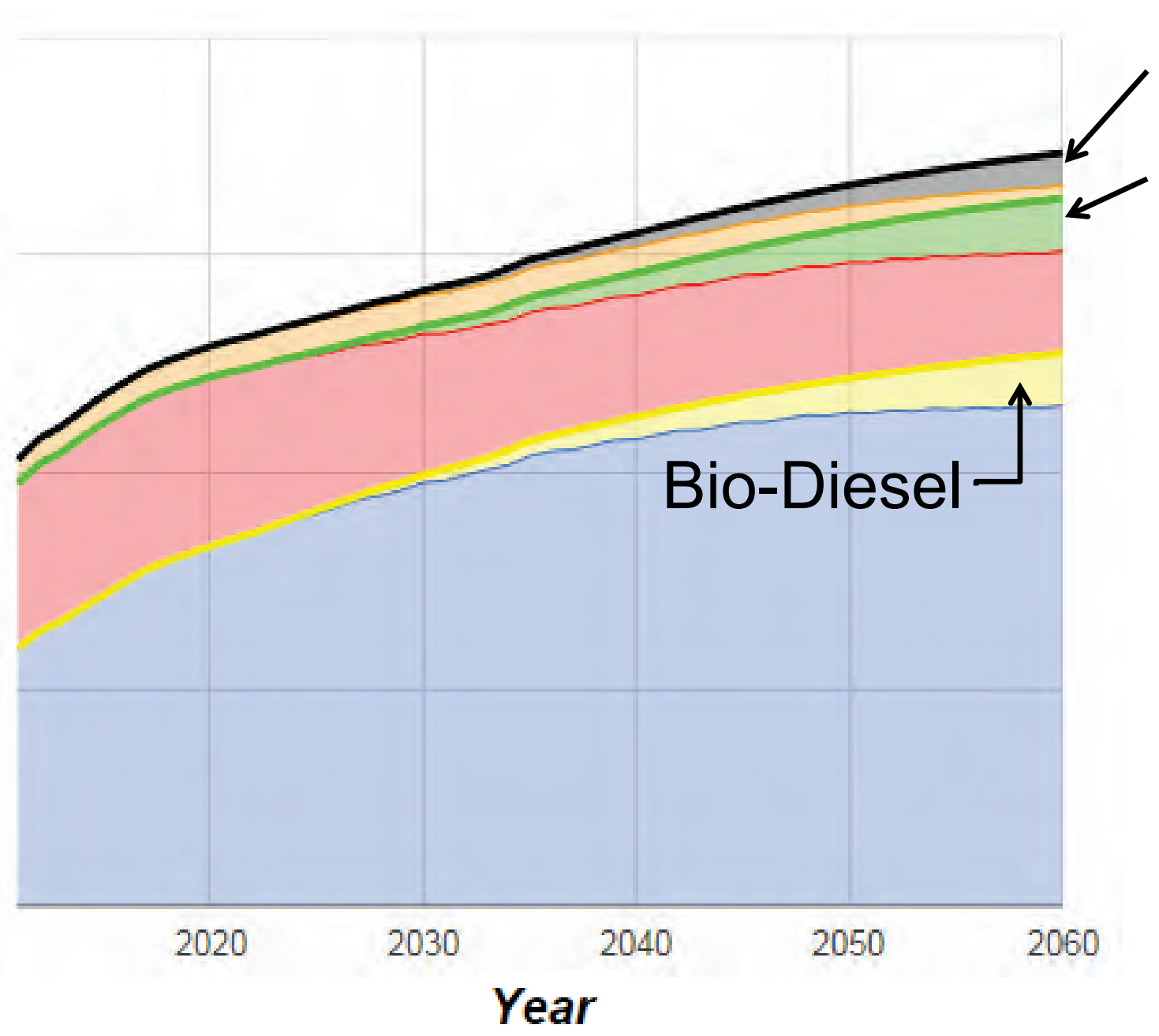

Fig. 4b Alt Fuel Production

Bio-Jet Fuel

Bio-Gasoline

Maximum Market Contribution:

- Jet Fuel: 71.9%
- Gasoline: 34.2%
- Diesel: 9.5%

Total Market Contribution: 18.3%

Lifecycle GHG Emissions

Takes into account the transportation, refining process and final engine combustion of fuels [3].

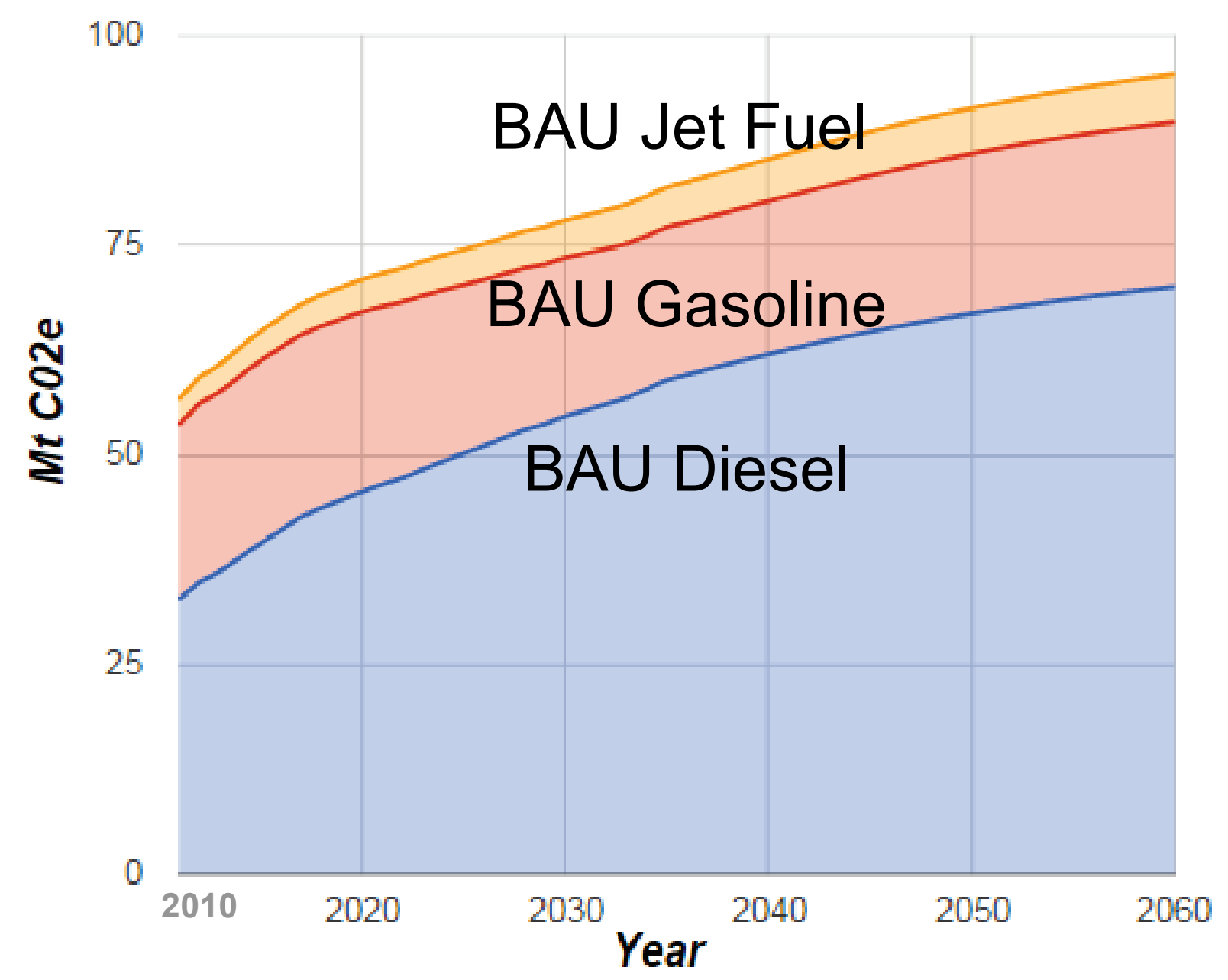

Fig. 5a Reference GHG

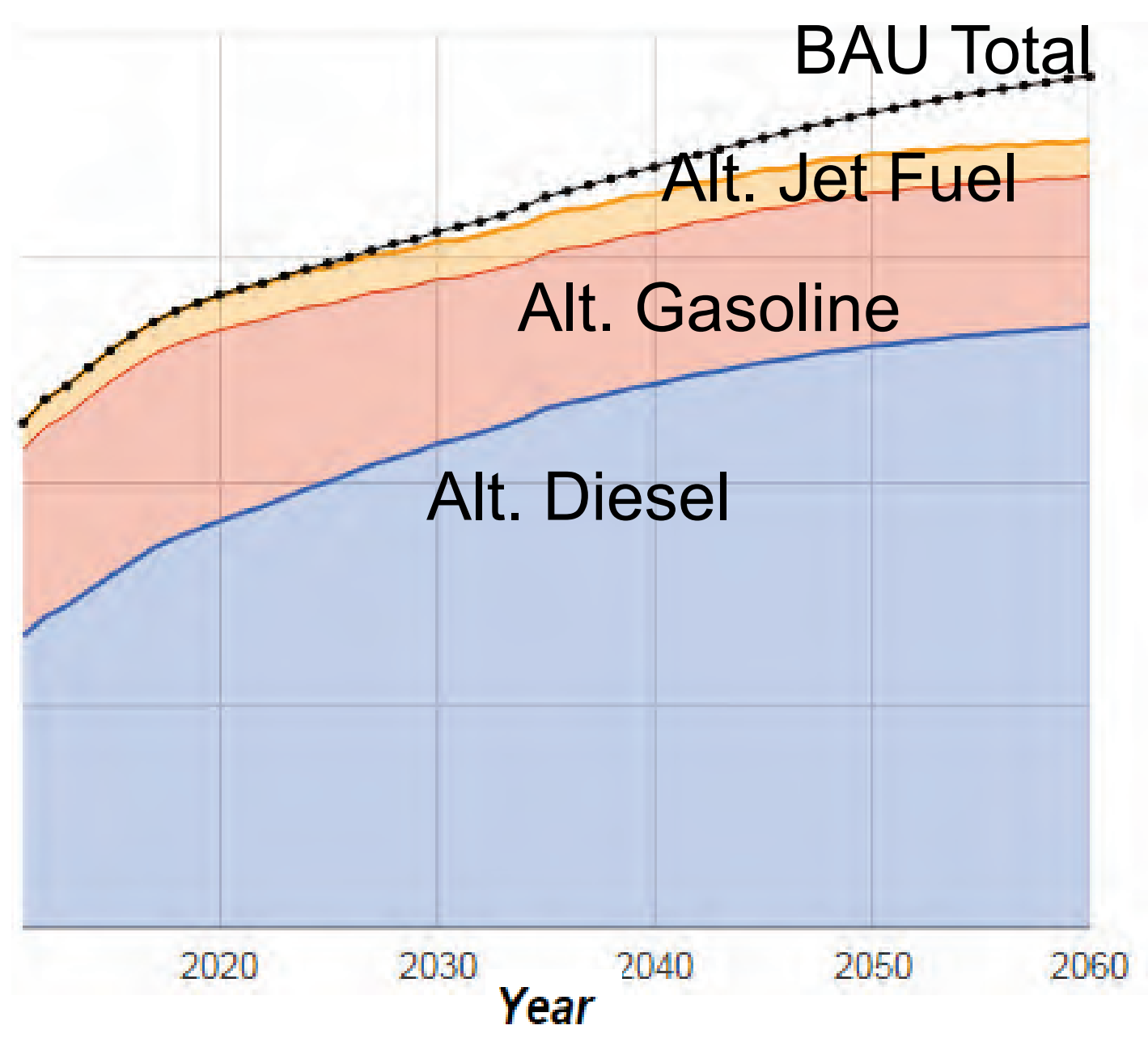

Fig. 5b Alternative GHG

7.16Mt CO_2e Reduction in 2060

Cumulative reduction since deployment: 127.5 Mt CO_2e

Comparative Carbon Prices

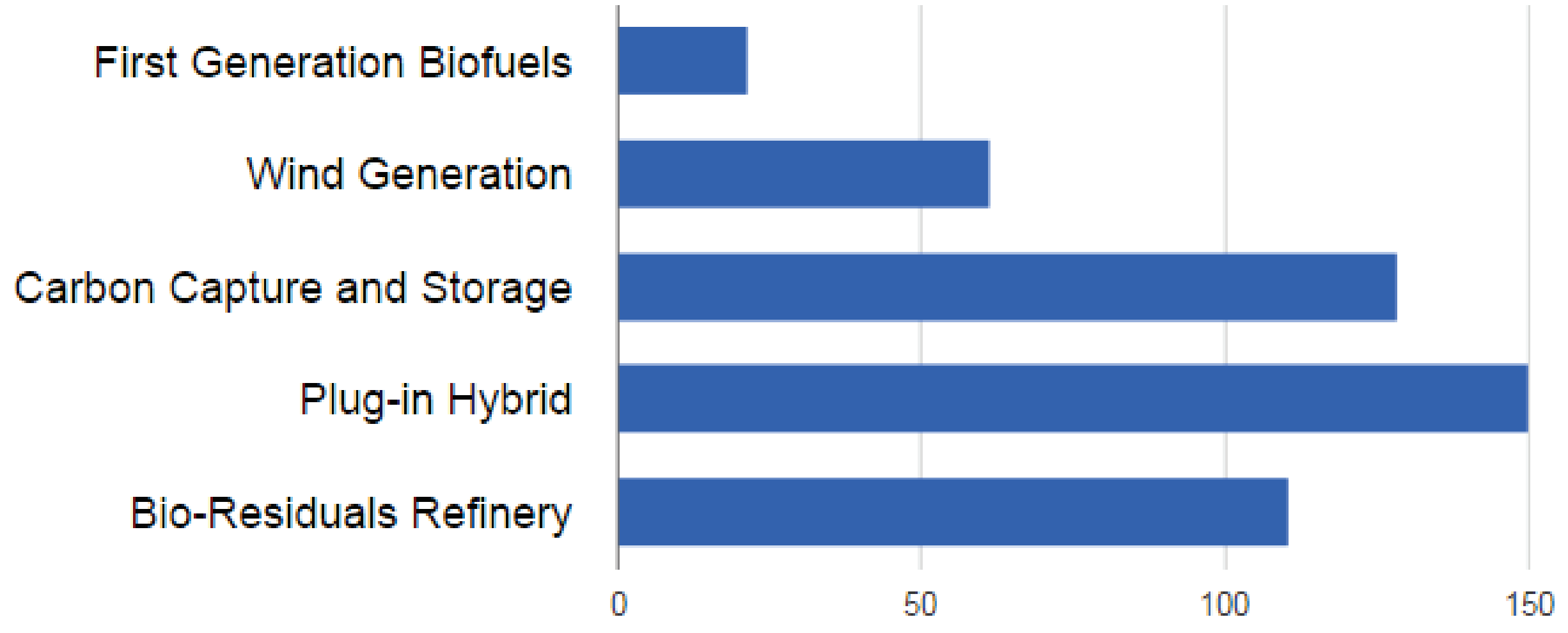

Fig. 6 Comparative Carbon Prices (CAD) [4]

Advantages

- Synthetic gas generation products such as this are very high quality
- Uses readily available resources
- Does not take resources away from food production

Disadvantages

- Feedstock has low energy density
- May lead to higher fertilizer use
- Heavy burden on transportation system

CONCLUSIONS

Fischer-Tropsch biofuel production has significant potential to reduce freight transportation emissions but at a high cost ($110/t$CO_2$e). This value corresponds to a 550% increase of current carbon price [5]. Our study examined the best-case scenario of bio-fuel production, therefore further research is recommended to achieve realistic application.

Given the high cost associated with this technology and the practical problems with transportation logistics, pursuing other climate change strategies is recommended at this time.

Some recommendations in order to potentially implement this technology in the future include:

- Policy on soil carbon
- Policy to improve rail infrastructure
- Policy to invest in Fischer-Tropsch technology

ACKNOWLEDGMENTS

We would like to acknowledge CESAR and the data they provided with the CanESS model , Dr. David Layzell and Dr. Bastiaan Straatman for their excellent instruction, and Dr. Josephine Hill for her expertise as our advisor.

REFERENCES

[1] Pinilla, M. (2011) *Comparative Life Cycle Assessments of Lignocellulosic and Algae Biomass.* University of South Florida.

[2] Alberta Agriculture (2011) *Census of Agriculture for Alberta.*

[3] Steenhof P., Woodsma C., Sparling E. (2006). *Greenhouse gas emissions and the surface transport of freight in Canada.* Transportation Research Part D 11.

[4] McKinsey&Company (2009) *Pathways to Low-Carbon Economy: Vs. 2 of the Global Greenhouse Gas Abatement Curve Cost.*

[5] Government of Alberta (2015) *Climate Leadership Plan: Carbon Pricing.*

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What's All The Hype On Hyperloops?

A transportation study for the Calgary-Edmonton Corridor


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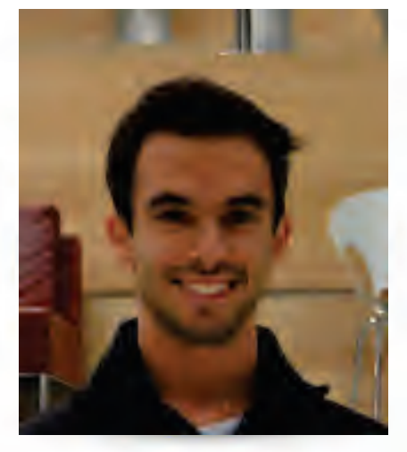
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INTRODUCTION

The movement of people and goods in Alberta generates 7.6 $MtCO_2e$ and is rapidly increasing due to the production and use of fossil fuels [1].

Pneumatically-driven Hyperloops have recently been proposed as a cost and energy effective intercity alternative [2][3]. Hyperloops function at extremely low air pressure and can reach speeds of up to 1200 km/hr.

This project explores the feasibility of a Hyperloop system implemented between Calgary and Edmonton, a corridor responsible for 40% of Alberta's transportation-related GHG emissions. We assess the potential reduction of energy consumption and emissions that would take place if this technology were to be deployed in Alberta.

METHODS

To examine the benefits of the Hyperloop technology in Alberta, a model of the historical and forecasted CO_2 emissions was constructed using MS Excel with the following assumptions:

- CanESS model forecasted values are accurate
- Freight movement between Calgary Edmonton is 30% of provincial movement
- The Hyperloop system is implemented by 2030
- Passenger ridership for Hyperloop is 60% of Calgary – Edmonton travel

		Passenger	Freight
Hours of Operation		18 hours	5 hours
Volume of Movement Annually (Calgary-Edmonton) (2030)		5.45 million passengers	757 million TKM
Movement/Capsule		28 people	37 tonnes
Cost of Travel		$72/Passenger	$30/tonne
Energy Consumption by Mode (2030)	Car	2.319 MJ/pkm	1.96 MJ/tkm
	Bus	0.32 MJ/pkm	
	Plane	1.4 MJ/pkm	
Energy Consumption (2030)		34.03 PJ/year	
CO2 Emissions by Mode	Car	0.5764 kgCO2/pkm	0.2989 kgCO2/tkm
	Bus	0.0891 kgCO2/pkm	
	Plane	0.1753 kgCO2/pkm	
Annual Emissions (2030)		4.36 MCO2e/year (2030)	
Maintenance		1 hour/day	

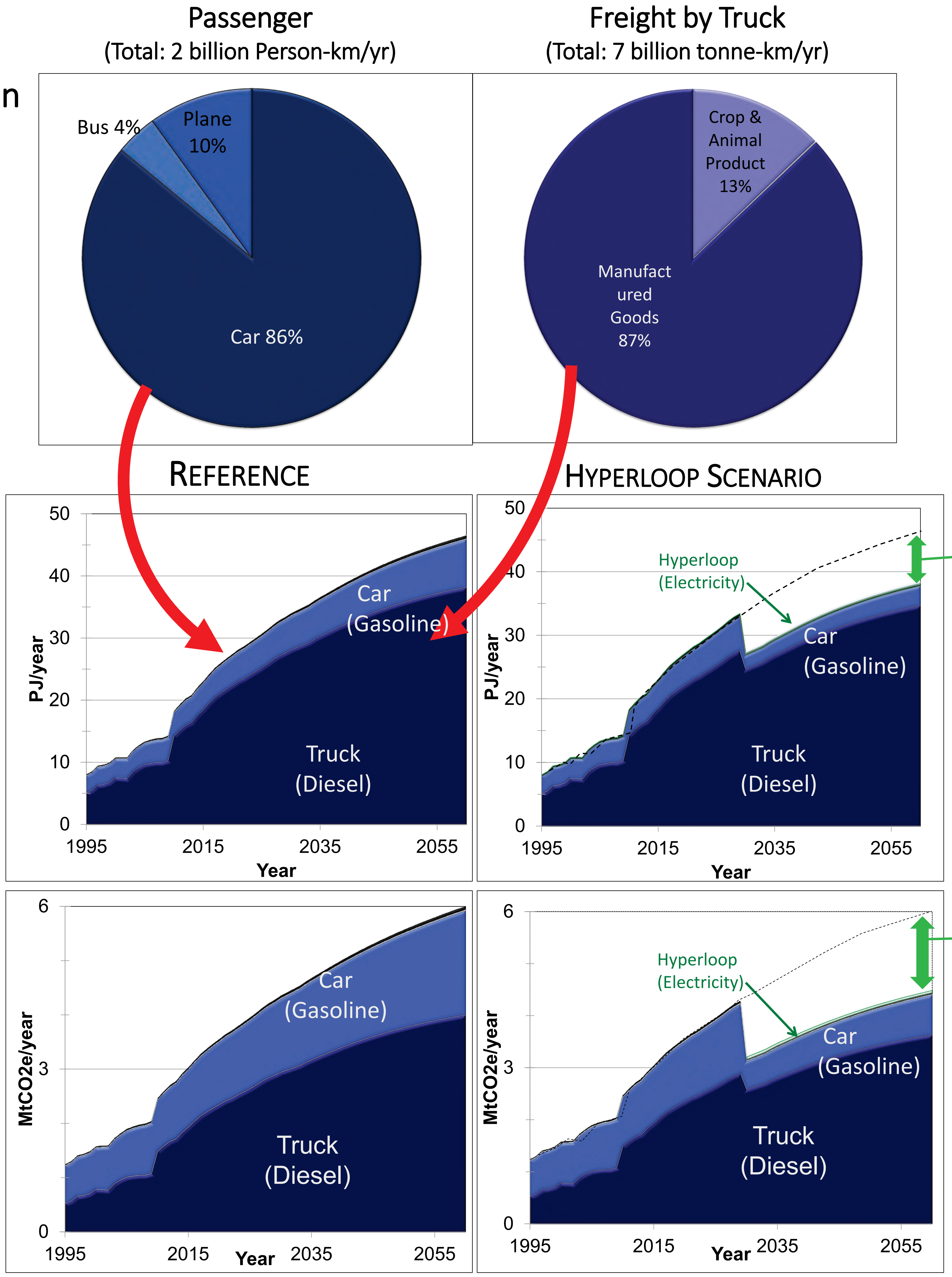
[6]

RESULTS

Transportation Estimates for the Calgary-Edmonton Corridor:

Energy Consumption (PJ/yr)

Life Cycle Greenhouse Gas (GHG) Emissions (Mt CO_2e/yr)



NOTE:

19% (6.6 PJ/yr) reduction in energy use in 2030.

NOTE:

26% (1.2 $MtCO_2e$/yr) reduction in GHG Emissions

Challenges & Opportunity

The Hyperloop provides the opportunity for creative thought on transportation adjustments to tackle provincial reduction in GHG emissions. However, it is challenged by the reality that ridership may not materialize, and Alberta may not be ready for such a large leap in transportation development. It is important to form an integrative system beyond the intercity stretch before true feasibility can be reached.

REFERENCES

[1] whatIf? Technologies Inc., 2014. Canadian Energy Systems Simulator (CanESS) - version 6, reference scenario. www.caness.ca
[2] SpaceX Hyperloop Alpha. Available at: www.spacex.com/hyperloopalpha.
[3] Evacuated Tube Transport Technologies: Space Travel on Earth. Available at: www.et3.com.
[4] Hyperloop picture retrieved from: http://mashable.com/category/hyperloop/.
[5] The Van Horne Institute: Updated Cost & Ridership/ Revenue for Calgary Edmonton High Speed Rail
[6] Kilograms of CO2 per passenger kilometre for different modes within the UK. Available at: http://www.aef.org.uk/downloads//Grams_CO2_transportmodesUK.pdf

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DISCUSSION

The Hyperloop may be a feasible option for reducing GHG emissions by reducing both passenger and freight traffic within the Calgary-Edmonton Corridor. Studied have analyzed the Hyperloop as sustainably economic mode relative to High Speed Rail [5], with a capital investment of $3.21 billion required including O&M [2] and ROI in 8 years. Although the schematics of implementation show a potential to reduce GHG emissions; Hyperloop technology is still limited to its research phase. There have been no comprehensive studies preformed for deployment in Alberta. Further development of the Hyperloop technology, and funding for scaled simulations will advance the concept into a more real Understanding of the technology will improve with research by Hyperloops Inc. in California. Do not despair, Elon Musk is on the job!

CONCLUSIONS

The Hyperloop has theoretically been estimated to reduce energy consumption and lower Albertan GHG emissions. A summary of our conclusions on the potential of a Hyperloop system in Alberta:

- Reduction of 6.6 PJ of energy consumption and 1.2 MtCO2e emissions in 2030
- By 2060, energy usage and carbon emissions reduced by 8.0 PJ and 1.5 MtCO2e respectively

These conclusions are interesting by means of the economic feasibility of development. Relative to the High Speed Rail proposal by the Van Horne which was deemed infeasible subsequent to full economic analysis within Calgary-Edmonton Corridor [5].

We suggest the Alberta government further analyze the Hyperloop alternative as it has conceptually proven to be cheaper and more efficient than other transportation alternatives.

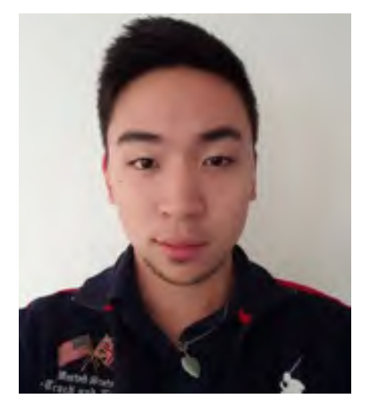
ACKNOWLEDGEMENTS

We would like to thank:

- whatIf? Technologies for allowing us to use their CanESS model
- Our extraordinary professors: Dr David Layzell, and Dr. Bastiaan Straatman
- Our expert advisor, Mr. Peter Wallis, and the Van Horne Institute for their guidance and insights
- The audience, for the opportunity to present our project!

THE DRIVE FOR SUSTAINABLE VEHICLES IN ALBERTA'S FUTURE

UNIVERSITY OF CALGARY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INTRODUCTION

The use of over 2.2 million personal vehicles in Alberta generates more than 8 Mt CO_2e of GHG emissions per year between vehicle production and fuel consumption. [2] Companies such as Google, Tesla and Uber are engaged in rapid innovation to transform personal transportation through the introduction of self-driving, electric and shared vehicles.

This study will use scenario modeling tools to assess the potential impacts of these technologies (together, a "Super vehicle", SV) on GHG emissions.

METHODS

To examine the impact of SVs in Alberta, we modified the reference model provided by CanESS [2]. In doing so, historical data from CanESS was extrapolated to project our scenario models to 2060. Assume:

- Adoption of SVs will reach maximum of 90% by 2055 (Figure 2) [3] [4]
- Alberta is 3 years behind compared to California with the same SV deployment rate [3]
- 60% of vehicles would be removed from the road (2 SVs can replace 5 conventional vehicles) [3] [5]

		MJ/100km		g CO_2e/MJ	
		2016	2060	2016	2060
Gasoline	City	464.7	294.9	67.5	67.5
	Hwy	306.6	182.9		
Diesel	City	412.2	264.1	71.3	71.3
	Hwy	272.3	166.7		
Electric (SV)	City	111.3	86.7	184	109
	Hwy	73.4	56.6		

Table 1: Important parameters from the CanESS model

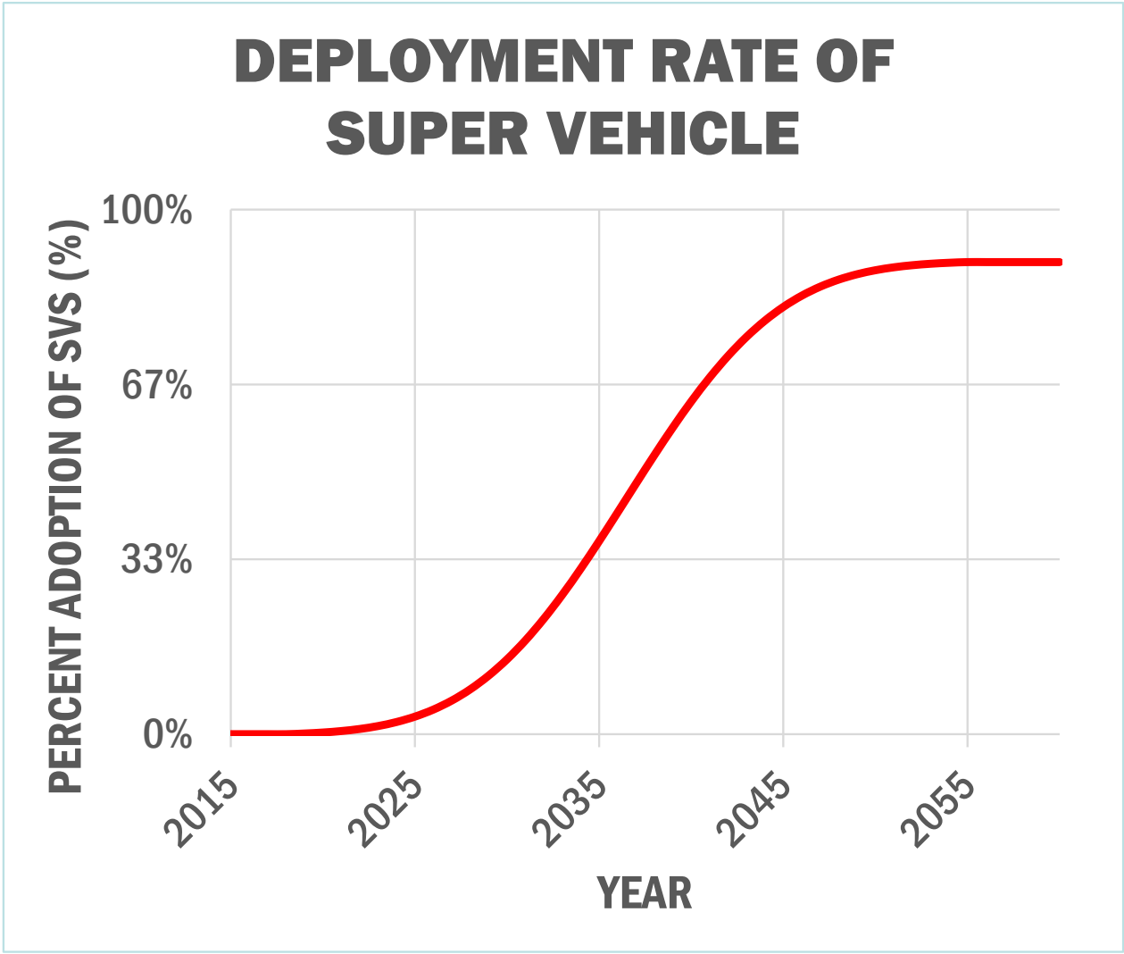


Figure 2: Adoption Rate of SVs

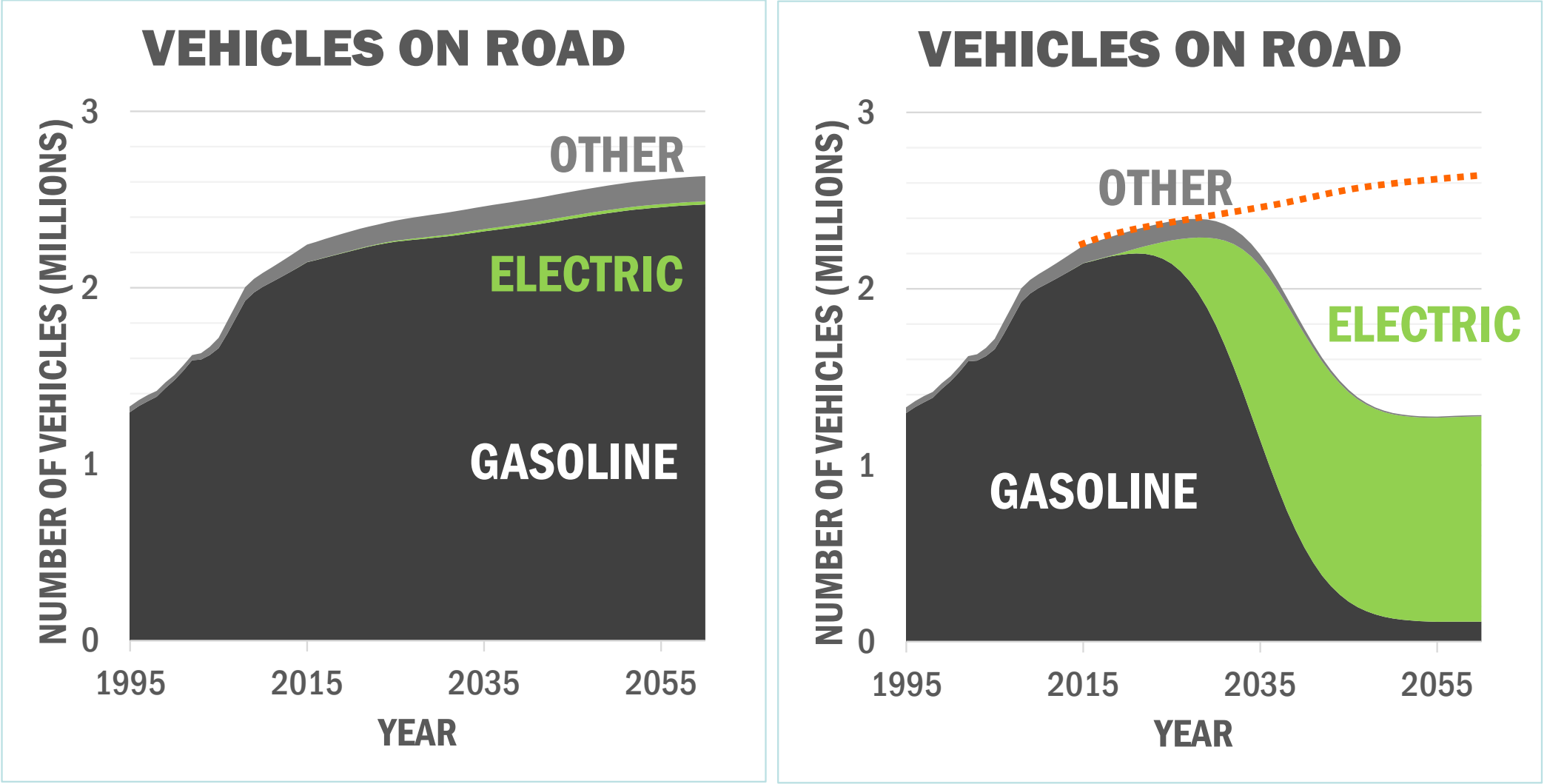
RESULTS

REFERENCE

ALTERNATIVE

Figure 3: Vehicles on Road

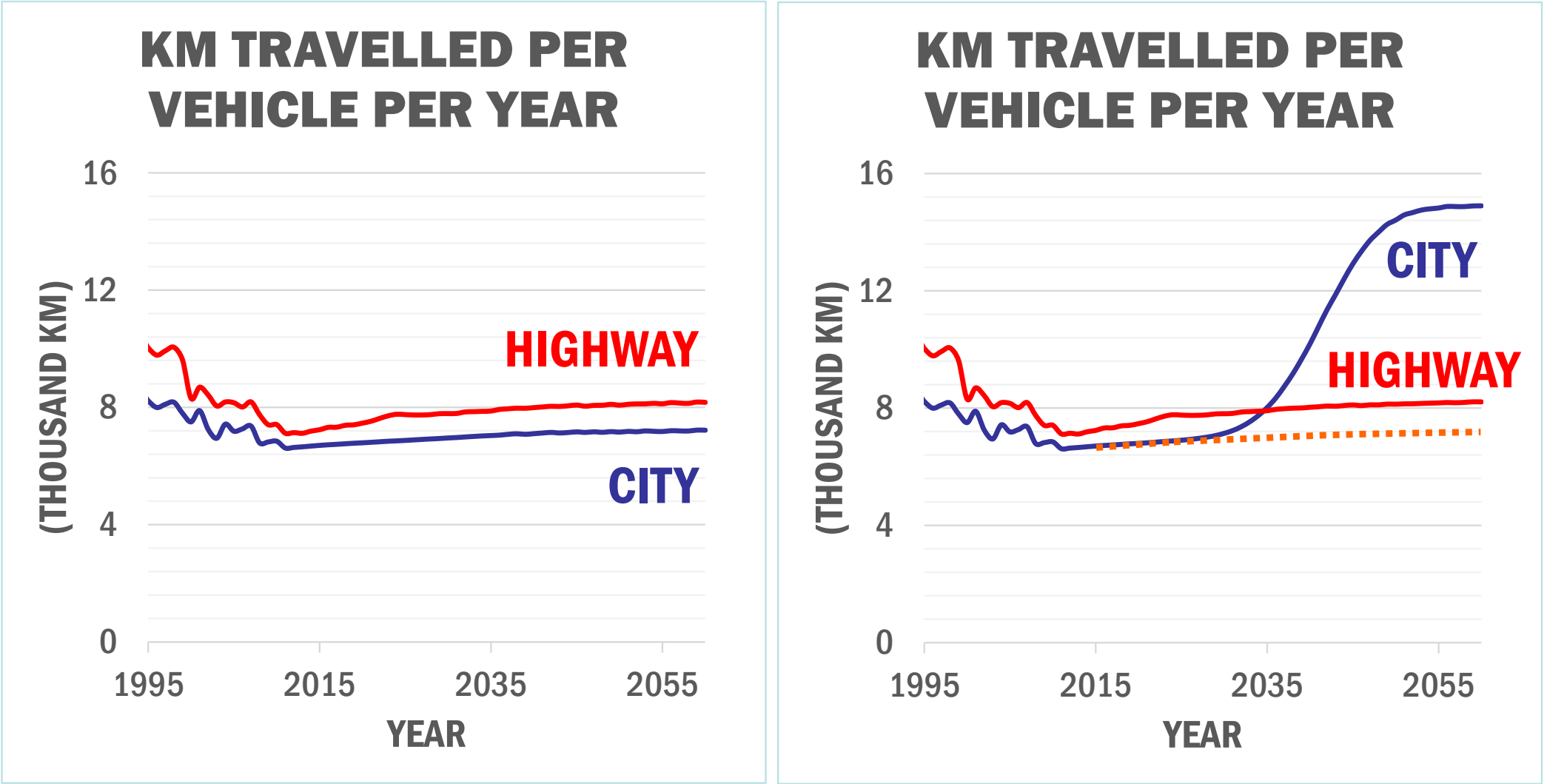
Without innovation and change, the number of vehicles will steadily increase until 2060.



Note the significant reduction in total number of vehicles on the road due to the use of car sharing.

Figure 4: KM Travelled per Vehicle per Year

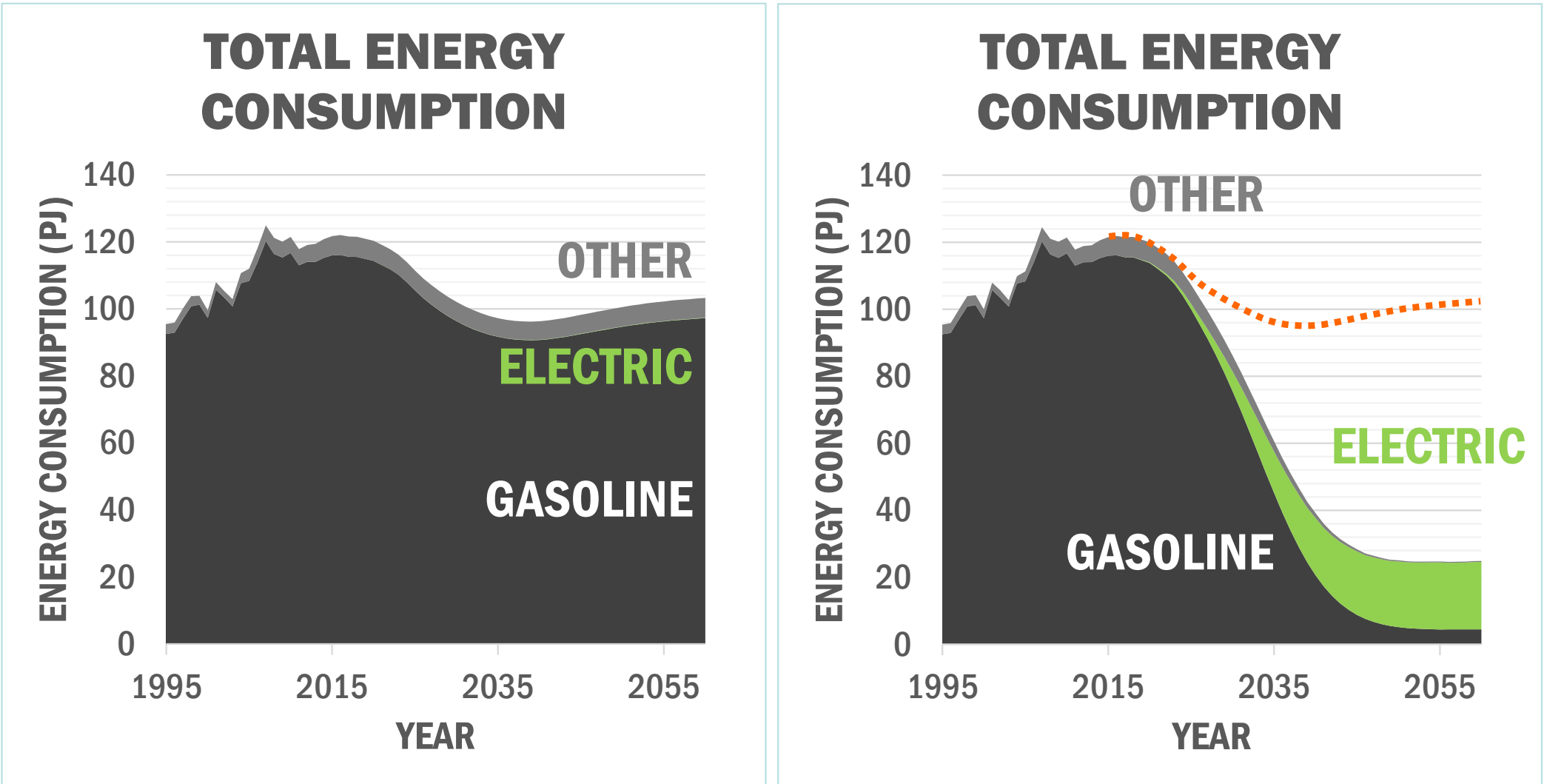
The CanESS model projects a stagnation of the distance people travel each year.



This will however increase the distance each vehicle travels in a year, at least in cities.

Figure 5: Total Energy Consumption

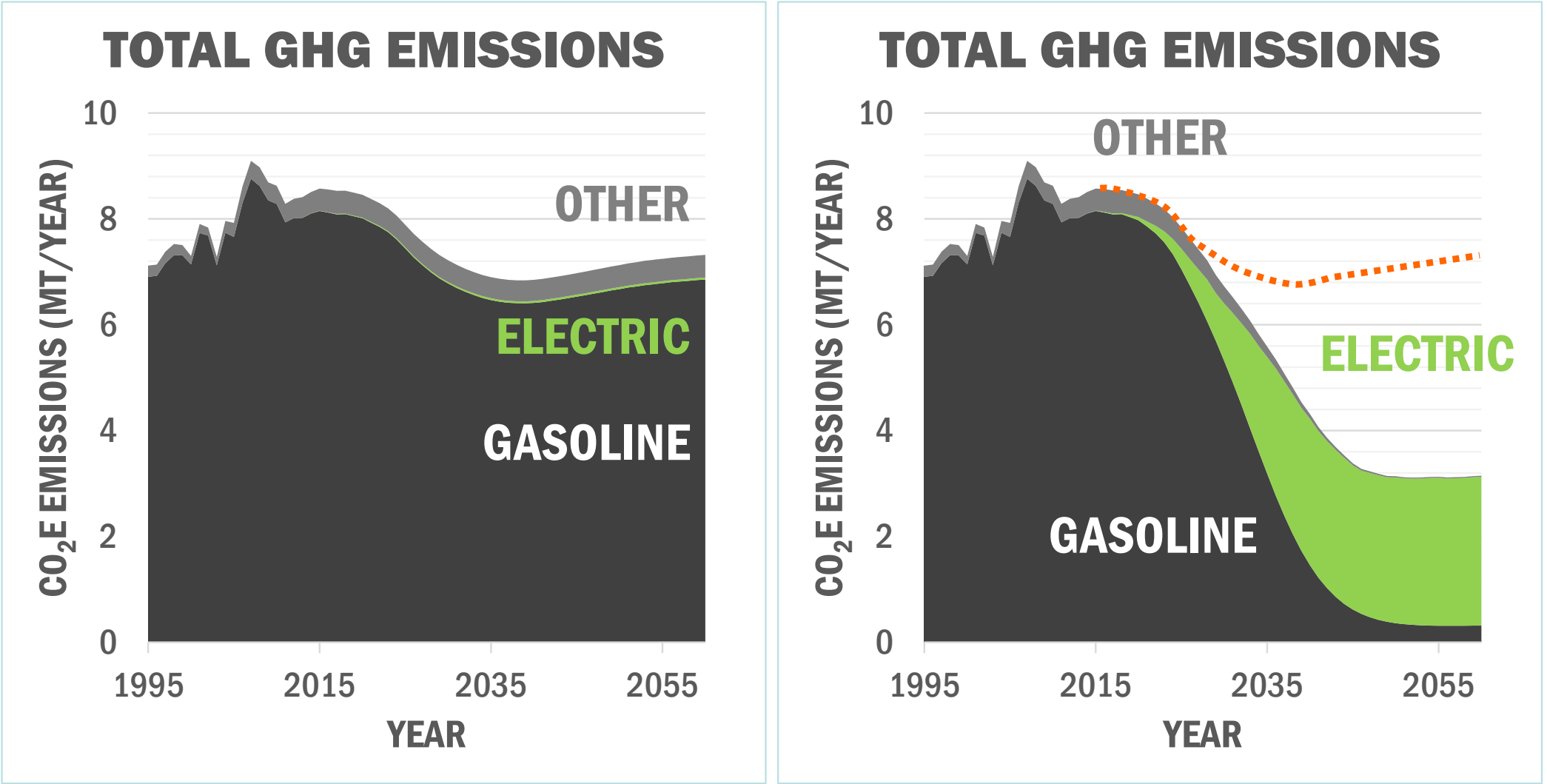
Increasing efficiency in the short term with a steady increase in vehicle count over time results in this trend.



The move to self-driving, shared electric vehicles will have a significant impact on energy consumption.

Figure 6: Total GHG Emissions

All of these factors add up to create the prediction depicted here.



This will significantly reduce GHG emissions, and will move emissions out of city centres, reducing pollution levels near densely populated areas.

REFERENCES

[1] The Conference Board of Canada. (2015). *Automated Vehicles. The Coming of the Next Disruptive Technology.* Retrieved from: http://www.cavcoe.com/Downloads/AV_rpt_2015-01.pdf

[2] whatIf? Technologies Inc., 2014. Canadian Energy Systems Simulator (CanESS) - version 6, reference scenario. www.caness.ca

[3] Godsmark, P. (2015, October 30). Telephone interview.

[4] McKinsey & Co., 2015. Ten ways autonomous driving could redefine the automotive world. http://www.mckinsey.com/

[5] Organisation for Economic Co-operation and Development, 2015. Urban Mobility System Upgrade: How shared self-driving cars could change city traffic. www.internationaltransportforum.org

[6] Aguirre, K., Eisenhardt, L., Lim, C., Nelson, B., Norring, B., Slowik, P., Tu, N. 2012. Lifecycle Analysis Comparison of a Battery Electric Vehicle and a Conventional Gasoline Vehicle. California Air Resources Board.

DISCUSSION

The main limitation of our study is that extrapolating from research done in the US and Europe to Alberta inherently poses some potential for error. [4]

To prevent potentially increasing GHG emissions and road traffic due to an influx of vehicles as self-driving cars become popular, car sharing policies and additional fees should be introduced to help prevent congestion.

Based on our results, driving emissions account for the majority of GHG emissions from personal transportation. The SV can reduce yearly driving emissions by 4.47 Mt by the year 2060. However, keeping into consideration the high production emissions of the SV [5], we can effectively reduce total yearly emissions by 4.17 Mt by 2060.

CONCLUSIONS

Super Vehicles are a viable and appealing option for sustainable transportation in Alberta. In our scenario, personal transport GHG emissions decrease by over 50% by 2060. Numerous economic, infrastructure, health and societal improvements are also made possible [4], making the SV a highly desirable mode of transportation [3]. In fact, companies like Google, Uber, and Tesla have been actively producing these vehicles in the U.S., saying that it is not a matter of if we will see these vehicles in the future, but a matter of when [1].

ACKNOWLEDGEMENTS

We would like to thank "whatif? Technologies" [2], our industry advisor Paul Godsmark from CAVCOE, and Professors Layzell and Straatman for their guidance in and data for this project.

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Residential Space Heating & Greenhouse Gas Emissions:

The impact of insulation, retrofits, size limits, and high furnace efficiency


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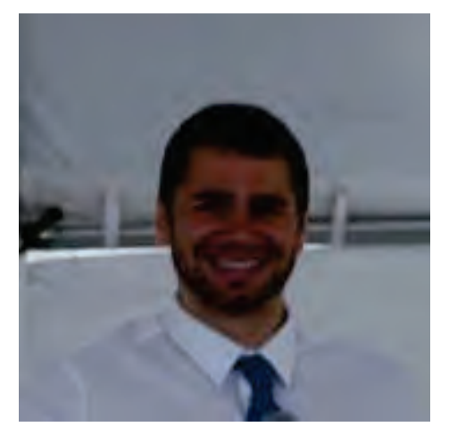
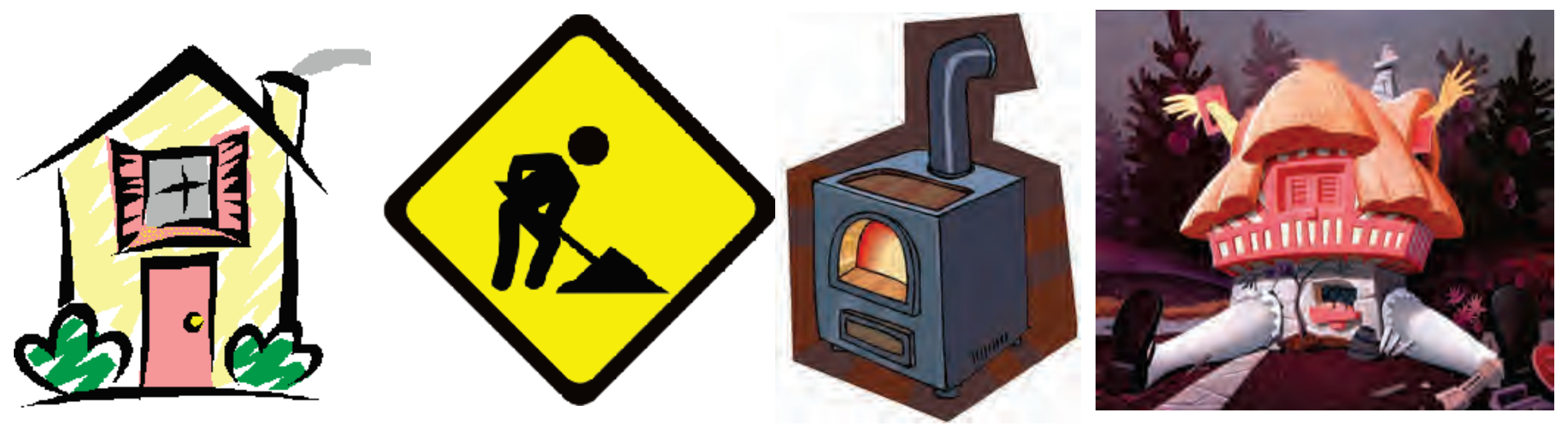

James Jenden
Natural Sciences

INTRODUCTION

Home heating demands account for **~9%[1] of Alberta's greenhouse gas emissions** and are expected to **increase by 40% by 2060** if no action is taken.

This project investigates four mechanisms to reduce these emissions:

1. Improve the Alberta Building Code (ABC) for new builds
2. Retrofit existing buildings
3. Legislate high efficiency (HE) furnaces
4. Encourage smaller homes



METHODS

An MSExcel© model was developed to calculate greenhouse gas emissions from single-detached residential houses in Alberta.

- **"Business as Usual" (BAU)** vs. **Improved building codes** and an energy efficiency **retrofit program.**
- BAU model was run using data provided by CanESS.[2]
- Natural gas was assumed to be the primary source of home heating energy[2] for the foreseeable future
- Figure 1 shows the calculated reductions in residential space heating possible through each mechanism.
- The 2015 average load is 0.67 GJ/m^2[2]

Factor	GJ/m^2	% Change
New ABC (new builds)	0.30	50%
Retrofit (old homes)	0.40	50%
High efficiency furnace	0.10	14%
Home size(new builds)	0	45%

Fig. 1 Table of possible space heating load reductions

RESULTS

BUSINESS AS USUAL SCENARIO

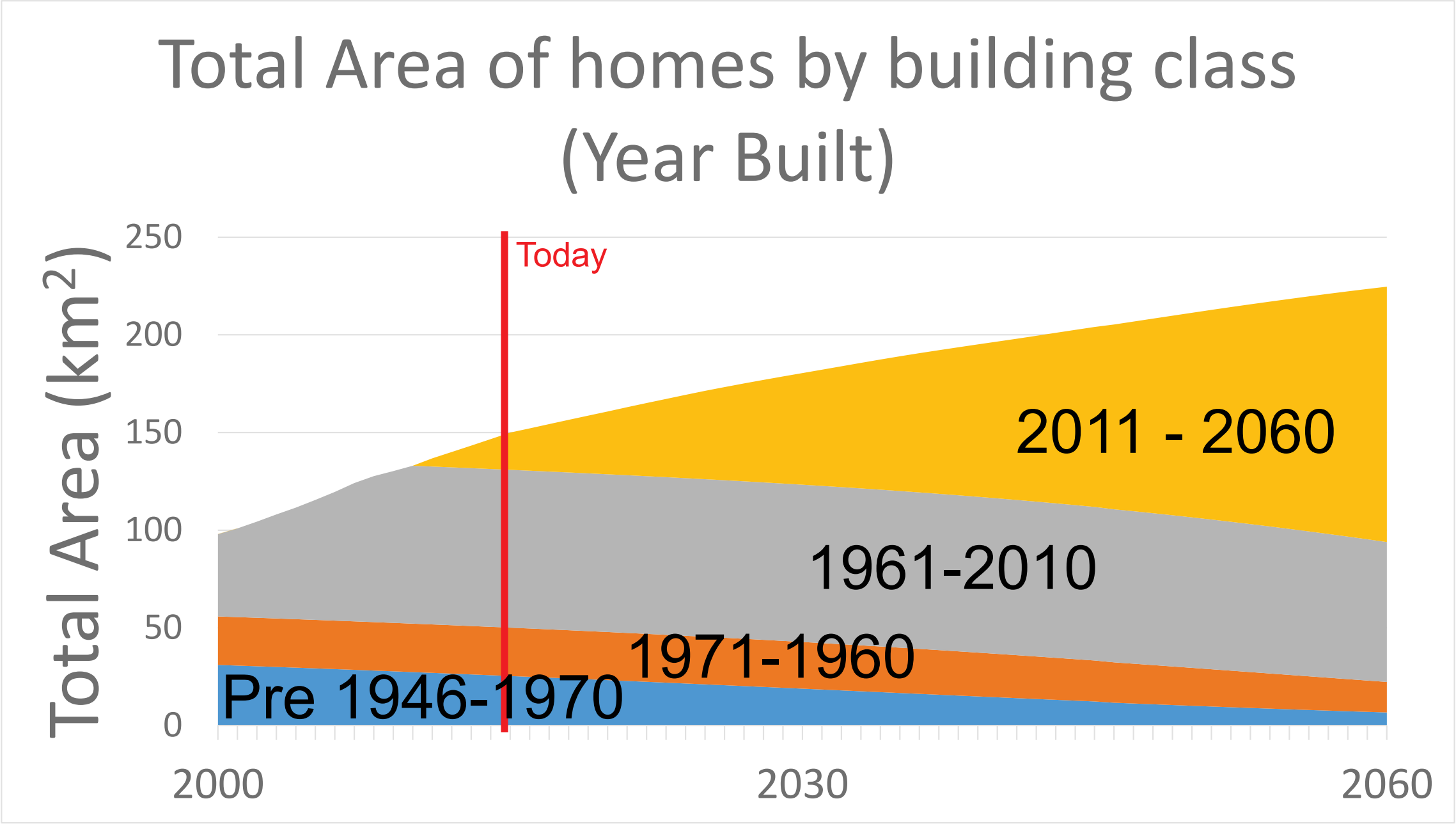


Fig. 2 Area of homes by building class

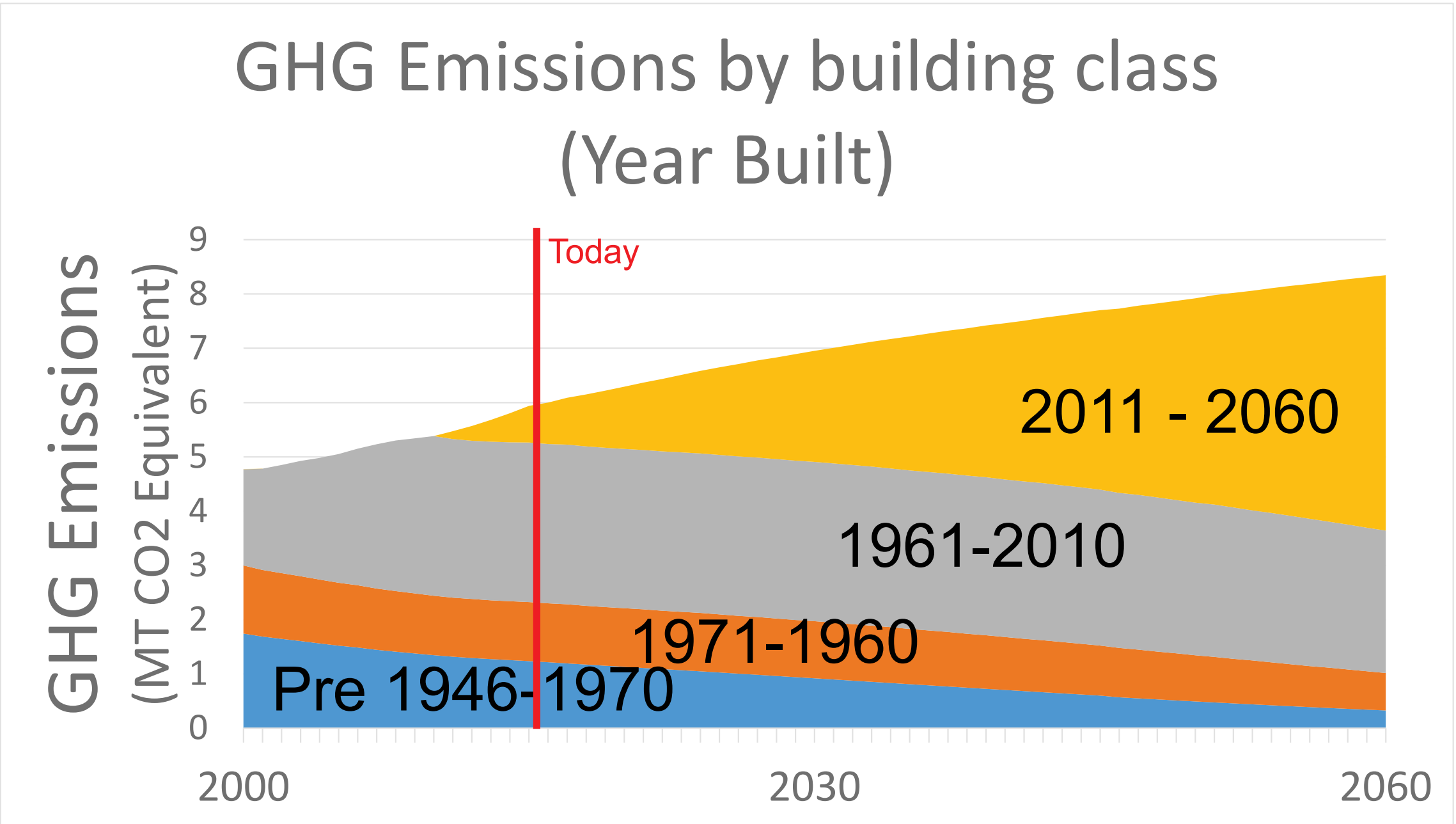


Fig. 3 GHG emissions by building class

ALTERNATIVE SCENARIO

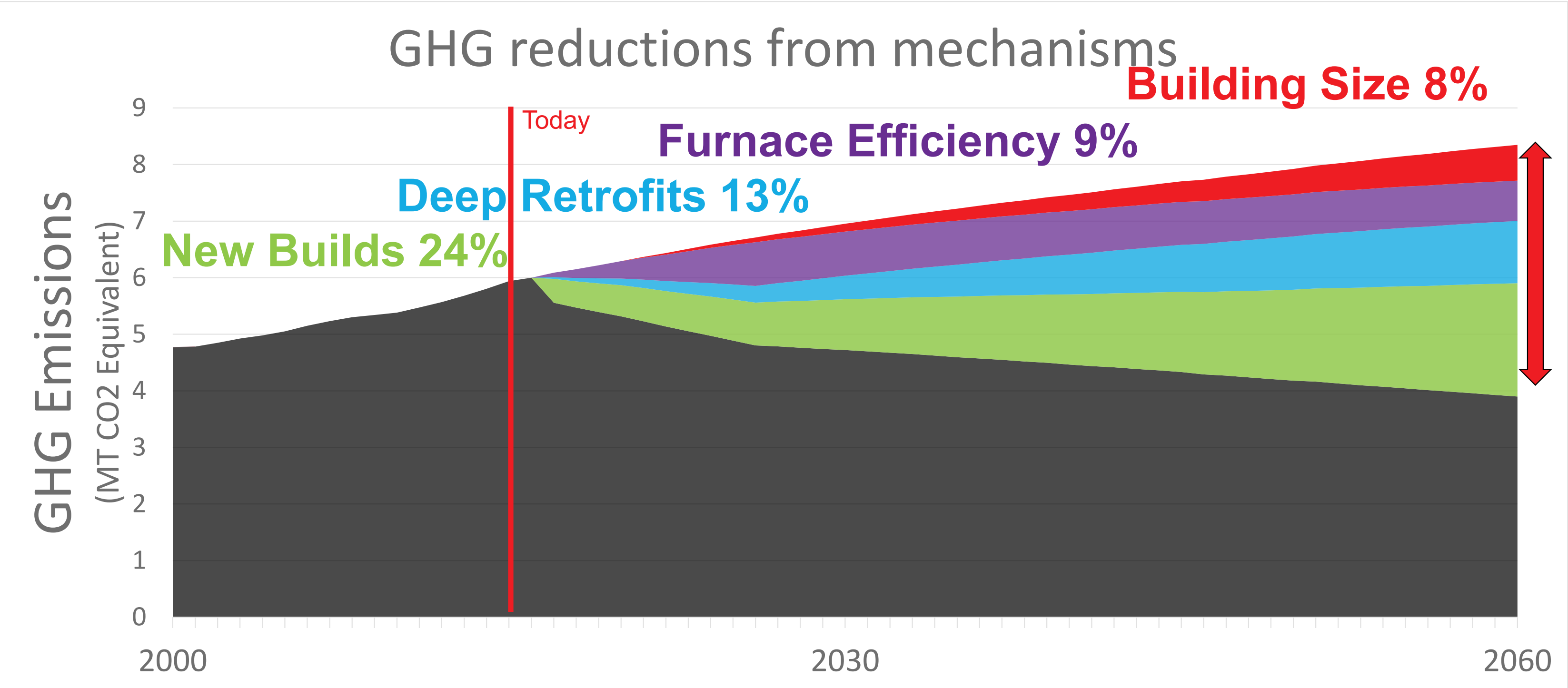


Fig. 4 GHG reductions due to mitigation measures

- Rapid reductions possible through HE furnace legislation and building code changes
- **Total reductions of 4.4 Mt per year at 2060**
- Mechanisms are ~50% more effective if taken individually
- New builds and retrofits could provide the greatest absolute reduction

Intervention Mechanism	Required Carbon Price Per Ton (For net zero cost to consumer)
Encourage smaller homes (average of 120m^2)	N/A
Legislate 95% efficient furnaces	$10
Legislate 98% efficient furnaces	$40
Reduce new build energy use by 50%	$100
Retrofit half of existing homes to use 50% less energy	$750

Fig. 5 Table of required carbon price to pay for each intervention mechanism

1. Savings on utility bills and carbon tax fees already make 95% efficient furnaces profitable
2. Changes to the building code could easily be accepted by public if carbon tax increased to $50 and incentive program were put in place to cover half of the costs
3. It is not very cost effective to use retrofit programs to reduce space heating GHG's in single detached homes

REFERENCES

[1] Mohareb E., and Row J. Improving Energy Efficiency in Alberta's Building Code. Pembina Institute. Alberta Real Estate Foundation, 2014. Web. 30 Sept. 2015.

[3] Straube, John. "BSD-011: Thermal Control in Buildings." Building Science Corporation. Building Science Corporation, 2 Nov. 2006. Web. 16 Nov. 2015.

[2] whatIf? Technologies Inc., 2014. Canadian Energy Systems Simulator (CanESS) - version 6, reference scenario. www.caness.ca

DISCUSSION

The greatest absolute GHG reductions can be achieved through an intensive deep retrofit program and a progressive building code.

The most financially feasible approach is a push to increase furnace efficiency provincially and to add smart-legislation on air barriers in the building code. **This result is similar to that found in literature.[3]**

This model could be enhanced by including study of the modal shift towards multi family dwellings like apartments (which have roughly ½ the space heating requirements of single detached homes)

CONCLUSIONS

Through a four pronged approach, depending on the level of mitigation intensity:

It is possible to reduce GHG emissions from residential space heating by at least 50% (4.4 Mt CO$_2$eq) by 2060 in comparison to a "business as usual" scenario.

This comes with an economic cost and potential political cost.

The key areas of focus are increasing furnace efficiency and air sealing of new builds.

ACKNOWLEDGEMENTS

We would like to thank the following contributors:
- WhatIf Technologies: CanESS Model Owners
- City of Calgary's Justin Pockar; our industry advisor

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Renewable Energy Storage in Alberta

Is it feasible to reduce greenhouse gas emissions in Alberta through energy storage and renewable energy sources?


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INTRODUCTION

In Alberta, 80 TWh of electricity generation per year produces greenhouse gas (GHG) emissions of 51 Mt CO2e/yr [1]. The coal-dominated public grid supplies 51% of provincial demand, and accounts for 81% of emissions. Recent provincial targets to drive coal generated power off the grid by 2030 [2] promote increased renewables (e.g. wind, solar) and energy storage technologies such as compressed air energy storage (CAES) and pumped hydro, in balance with natural gas (NG) turbines. This study draws on recent estimates of the optimal balance between renewables, gas turbines and storage [3][4][5] to develop a scenario for greening the grid in Alberta.

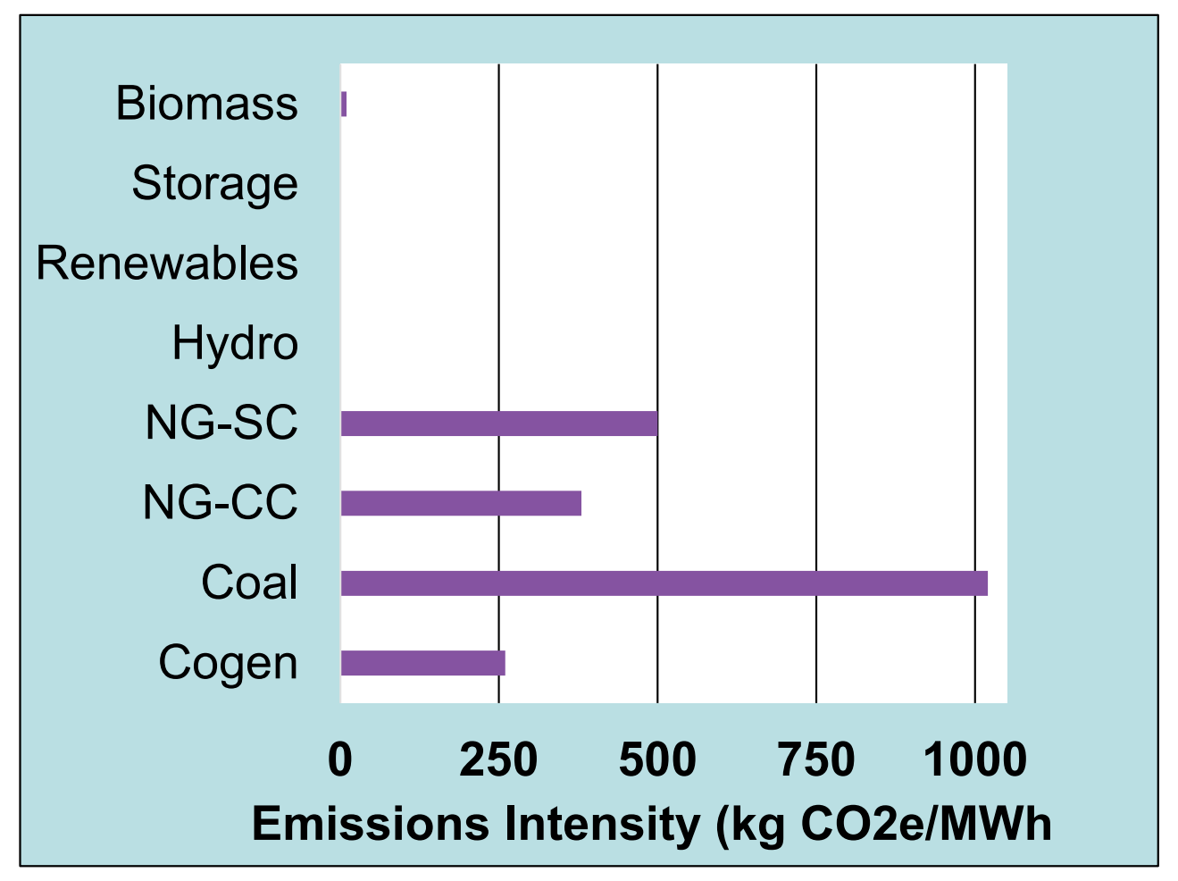

Fig. 1. Emission intensity of various electricity sources on the Alberta energy grid.

METHODS

The majority of the data used in the Business as Usual (BAU) scenario was obtained from a CanESS model provided by whatIf? Technologies [1]. In the alternative scenario (AS), 270 MW of electricity capacity from CAES are introduced in 2019. 1500 MW of pumped hydro capacity is added in 2020, increasing to 3000 MW in 2025 and 6000 MW in 2040.

Renewable energy added	438 MW/year starting in 2017
Percentage of wind into storage	40%
Efficiency of storage	90%
Ratio of gas turbines to wind capacity	0.62
Efficiency of NG-SC	35%
Percentage of pumped hydro from BC to AB	60%
Percentage of wind generated onto the grid	60%

Table 1: Factors and efficiencies used in the AS [3][5]

RESULTS

A. Electricity Capacity

- BAU: Coal is phased out over the next 50 years, replaced by combined cycle natural gas (NG-CC) and wind
- AS: Coal is phased out by 2034, replaced by renewable energy sources and associated storage.
  - Simple cycle natural gas (NG-SC) capacity to provide backup to renewables

B. Electricity Generation

- AS: New electricity generation values calculated for NG-CC, renewables and storage.
- Renewables assumed to have 100% efficiency.

C. GHG Emissions

- Phasing out coal plants earlier than anticipated, increasing renewable energy sources and storage results in significant reduction of GHG emissions.
- NG-SC is the only carbon-intensive addition to the grid.

D. Potential Revenue from Carbon Tax

- $20 carbon tax (2017), $30 carbon tax (2018), increases yearly
- AS: $1.2 billion in potential carbon tax revenue (2018), decreases to $438 million (2060)

BUSINESS AS USUAL **ALTERNATIVE**

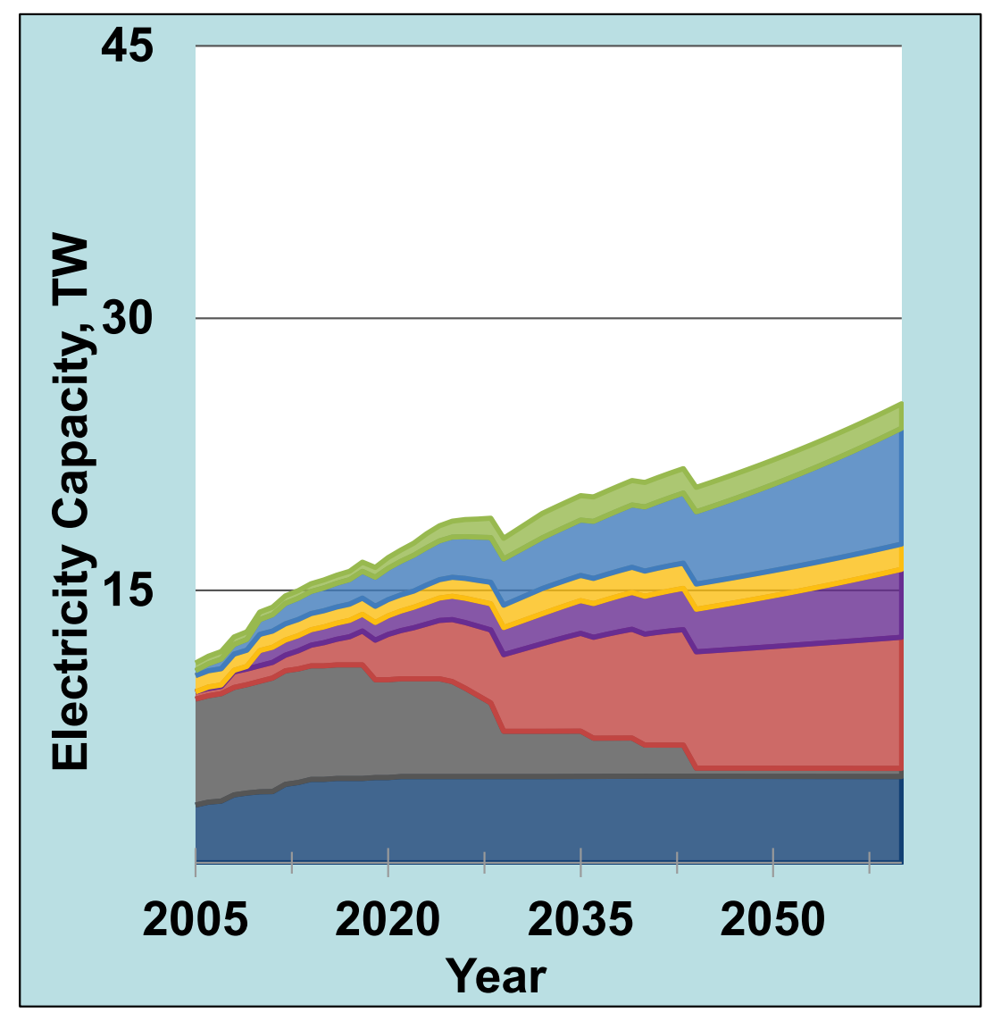

Fig. 2a. BAU: Electricity Capacity

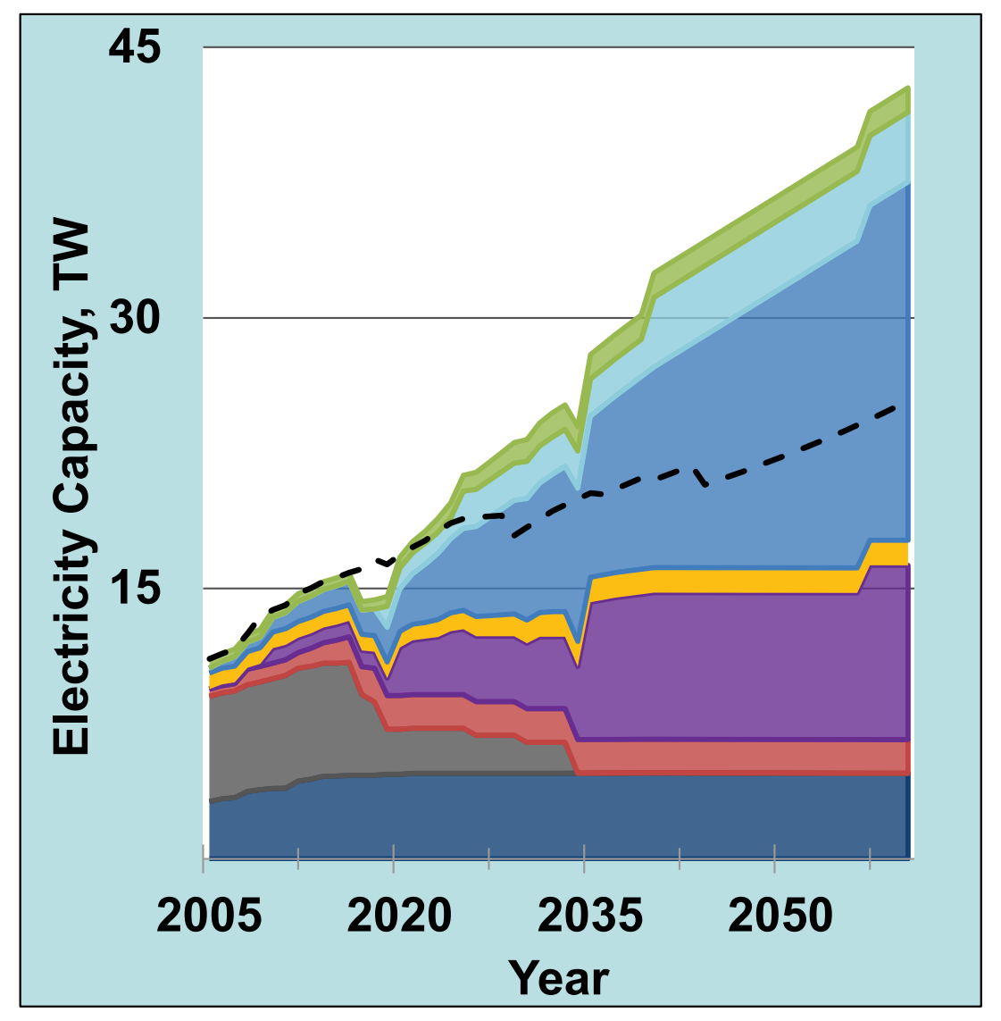

Fig. 2b. AS: Electricity Capacity

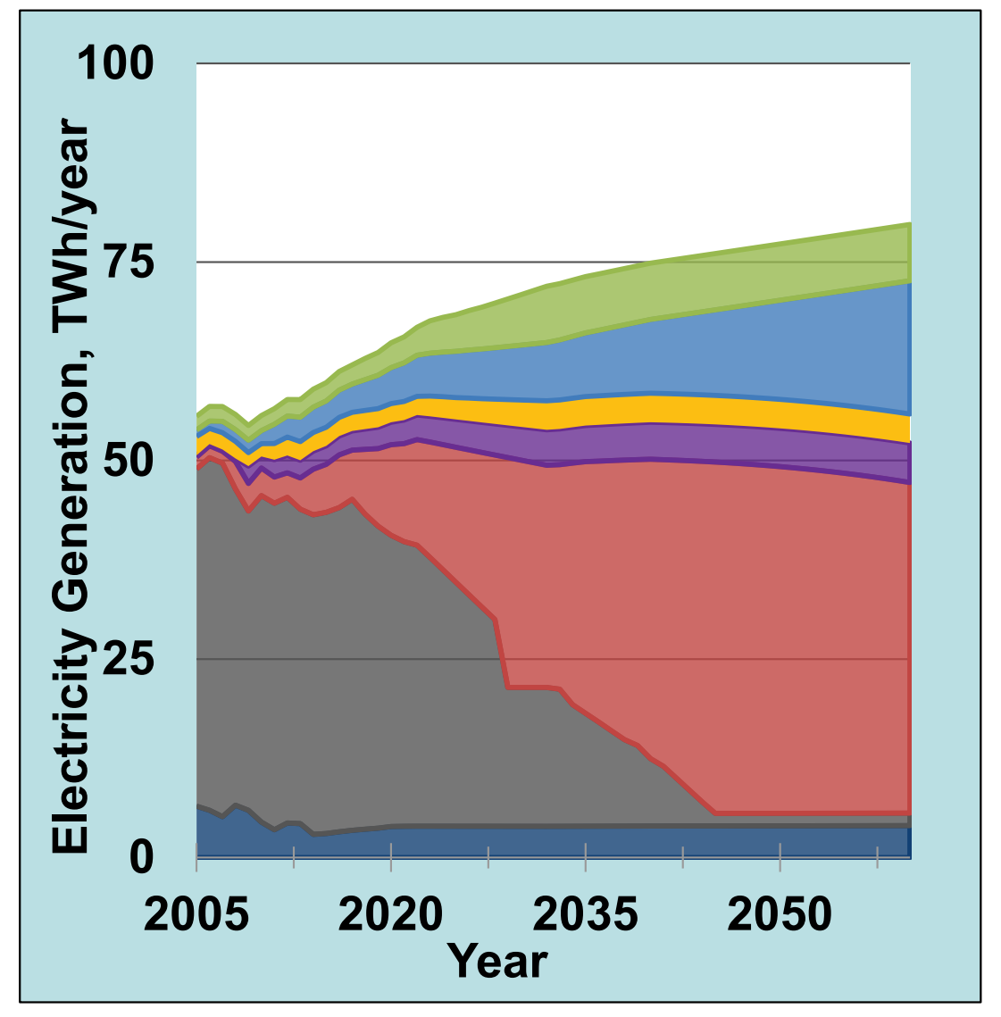

Fig. 3a. BAU: Electricity Generation

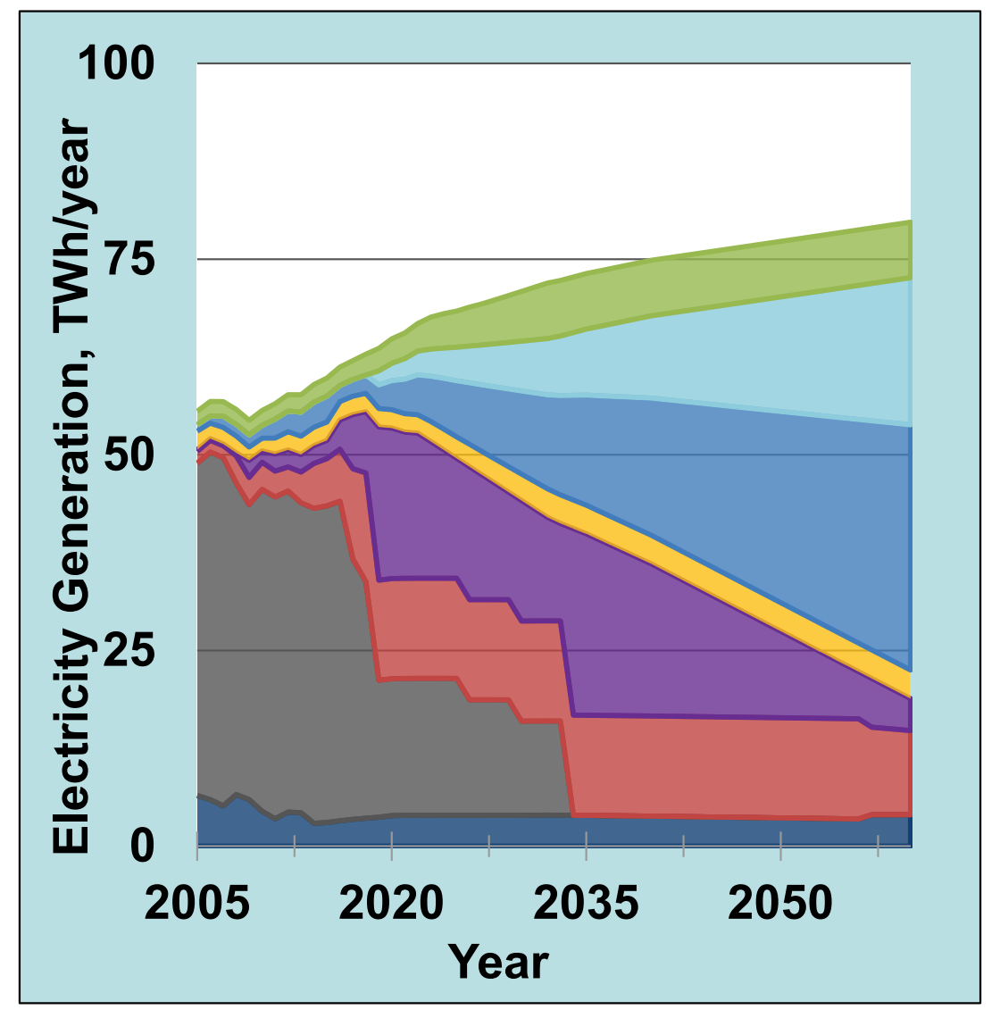

Fig. 3b. AS: Electricity Generation

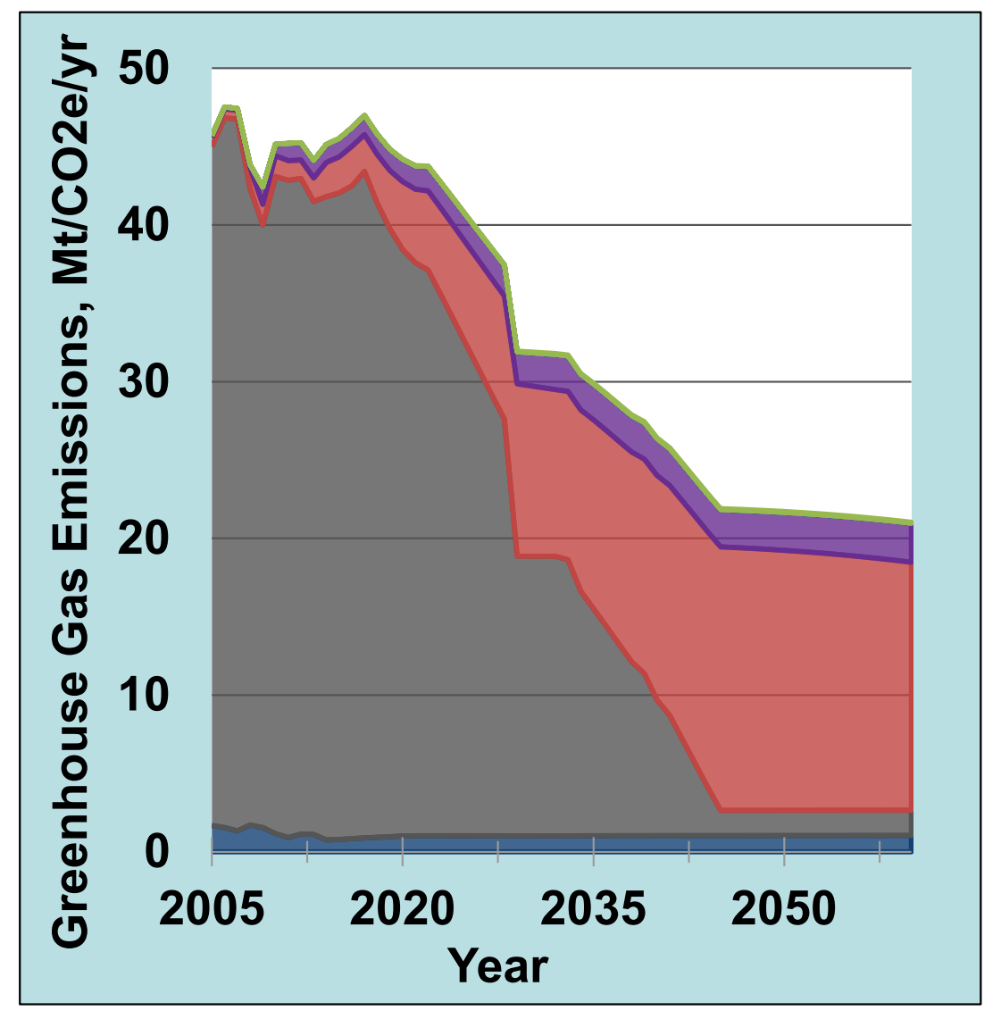

Fig. 4a. BAU: GHG Emissions

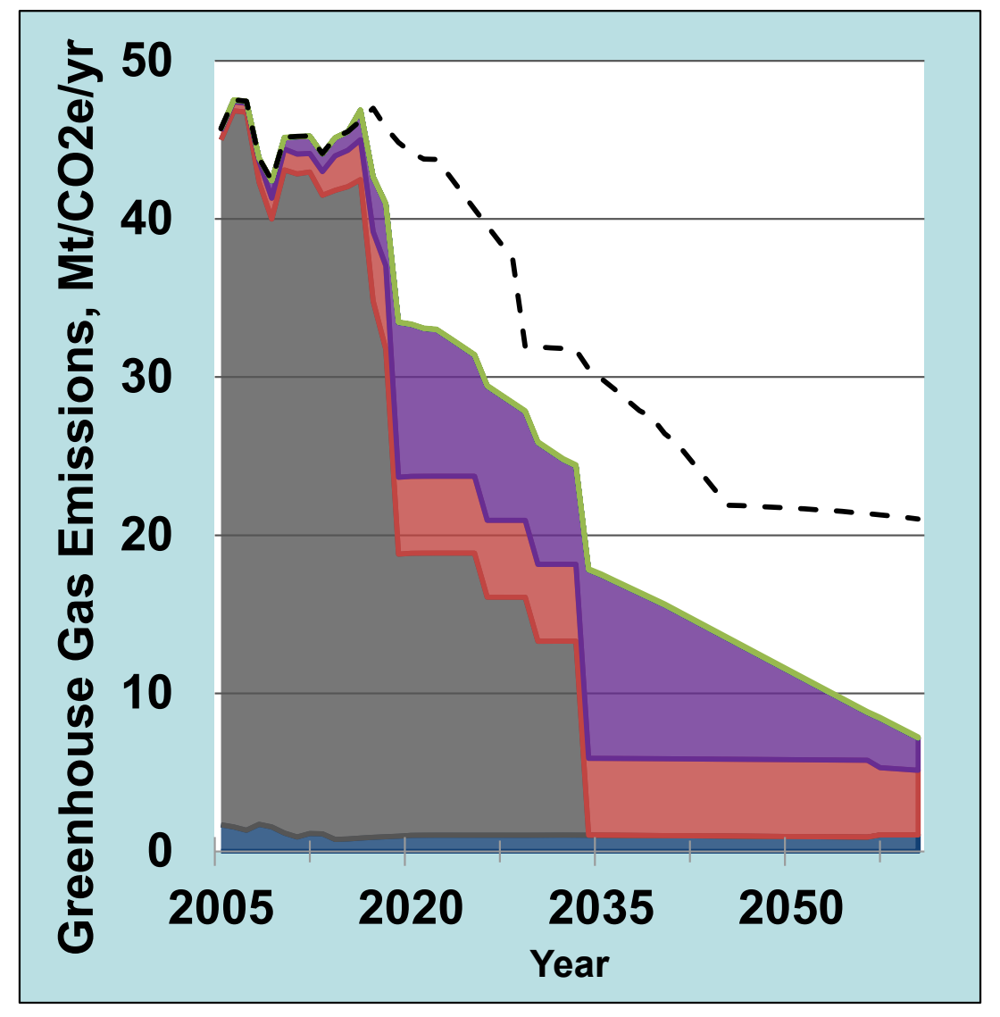

Fig. 4b. AS: GHG Emissions

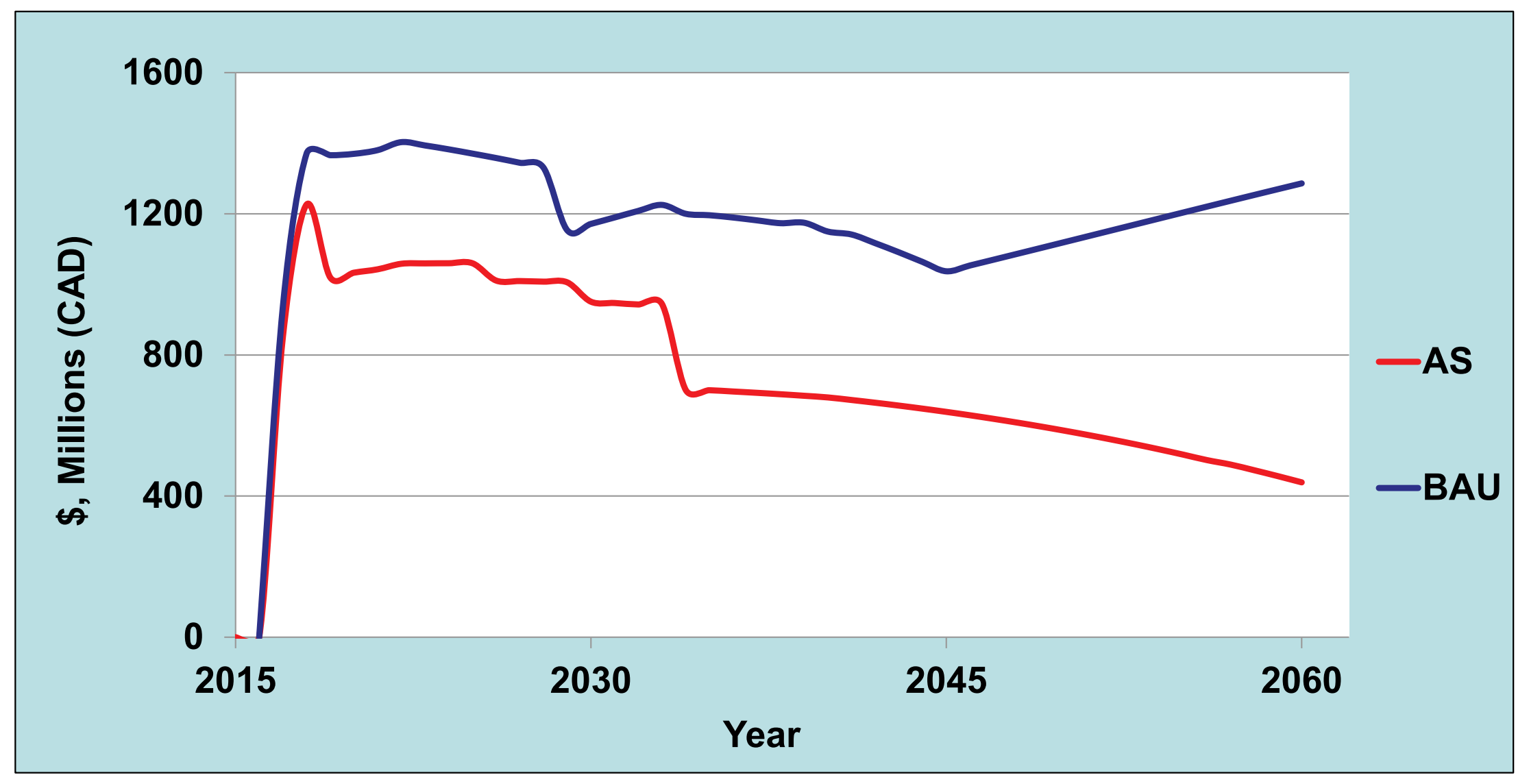

Fig. 5. BAU vs. AS: Potential Revenue from Carbon Tax Initiatives

Legend
For Figures 3-5

🟩 Biomass	🟪 NG-SC
🟦 Storage	🟥 NG-CC
🟦 Renewables	⬛ Coal
🟨 Hydro	🟦 CoGen
	– – BAU

NOTE:

IN THE ALTERNATIVE SCENARIO…

- ➢ Values shown are for public grid, excluding behind the fence for Fig.3a,3b & Fig.4a,4b
- ➢ Electricity capacity is increased by 70% from the BAU scenario (Fig. 2)
- ➢ Dips in electricity generation (Fig. 3b, 4b) signify the closing of coal plants
- ➢ A total GHG emission reduction of 441 Mt CO2e between now and 2060 (Fig. 5)

DISCUSSION

Coal capacity can be minimized using renewable energy sources and associated energy storage such as CAES and pumped hydro. NG-SC must also be deployed along with the storage options to ensure grid reliability, limiting the overall effectiveness of renewables in Alberta's energy grid.

Past studies evaluated the economics of CAES and pumped hydro[3][5][6]. They suggest wind power with pumped hydro could economically meet peak load requirements in Alberta, but do not specify reduction to GHG emissions [3][6]. Our study specifies possible reduction in GHGs, which could guide policy decisions. Our study also closely matches the targets set in Alberta's Climate Leadership Plan [2]; the targets for coal elimination and 30% renewable generation are delayed by only four years.

NG turbines costs will decrease with time and are sensitive to fiscal changes [7]; a decrease in prices could threaten the economic viability of clean energy in Alberta's future. A carbon tax could help fund these technologies. A more comprehensive study is necessary for levelized cost of electricity and optimization in Alberta, in order to determine the economic feasibility.

CONCLUSIONS

Phasing out coal plants at an accelerated rate and replacing their capacity with renewable energy sources and energy storage would result in 441 Mt CO2e saved from now to 2060. This scenario is viable when using wind and solar power with pumped hydro. A carbon tax could help fund these technologies. However, further economic studies must be done.

REFERENCES

[1] whatIf? Technologies Inc., 2015. Canadian Energy Systems Simulator (CanESS) - version 6, reference scenario. www.caness.ca

[2] Alberta Government (2015). *Climate Leadership Plan.* Retrieved November 25, 2015 from: http://alberta.ca/climate/leadership-plan.cfm

[3]Hydro Battery Inc. (2015). *The Hydro Battery Proposal for British Columbia and Alberta's Electrical Systems.* Retrieved from: http://www.arfd.gov.bc.ca/ApplicationPosting/getfile.jsp?PostID=50196&FileID=59902&action=view

[4] Straatman, B., Layzell,. D. (2015, November). Personal communication.

[5] Safaei, H., & Keith, D. (2015). How much bulk energy storage is needed to decarbonize electricity? Energy Environ. Sci. doi:10.1039/C5EE01452B

[6] Benitez, L.E. Benitez, P.C., van Kooten, G.C. (2008, July). The economics of wind power with energy storage. *Energy Economics. Volume 30, issue 4*, pp. 1973 – 1989 doi:10.1016/j.eneco.2007.01.017

[7] Colpier, U.C., Cornaldn, D. (2002, March). The economics of the combined cycle gas turbine—an experience curve analysis. *Energy Policy. Volume 30, issue 4*, pp. 309 – 316. doi:10.1016/S0301-4215(01)00097-0

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Alberta Energy System: A Focus on Diet

The Impact of Dietary Trends on Alberta's Greenhouse Gas Emissions


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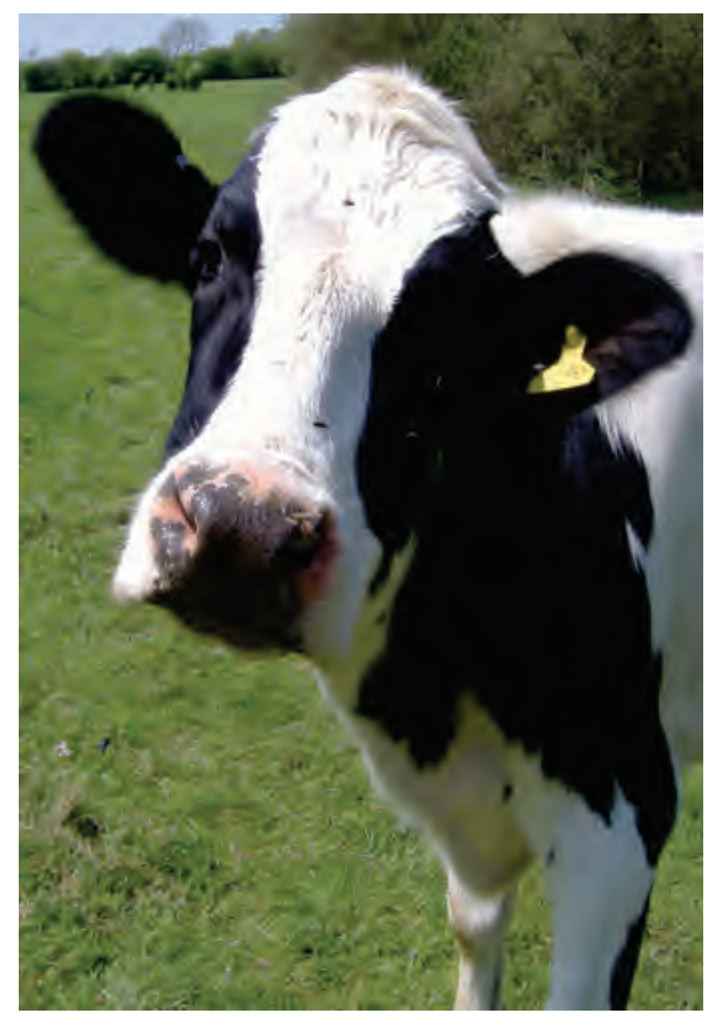
INTRODUCTION

Agricultural production in Alberta generates about **16 Mt CO_2e/yr** of greenhouse gas (GHG) emissions, and uses **20.4 Mha** of land. Animal production, the majority of which is beef, accounts for 78% of these emissions.

While Alberta is home to only 11% of the Canadian population, its cattle industry supplies approximately 41% of the nation's beef [1], the remainder being exported to the US, with a small percentage sold overseas [2].

North American red meat consumption has been in decline for the past decade [3]. The change has been primarily driven by higher meat costs as well as medical studies linking red meat intake to a number of health risks [4]. Another emerging driving force has been the widespread awareness over the environmental footprint related to red meats. This is especially true of beef, given that it is a very carbon-intensive protein source.

This study analyzed how Alberta's agricultural industry will be affected as individuals look to replace red meats with other protein sources, such as chicken or beans. The resulting GHG emissions, land use changes and revenue losses from production were considered.



METHODS

The **Holos farm modelling software** [5] and **Stats Canada data** [1] were used to calculate GHGs resulting from agriculture in Alberta, on a per unit basis for each type of product.

Dietary changes were modeled in two scenarios, where beef consumption is reduced by half and replaced with either chicken or beans. The dietary change is assumed to take effect over a **35-year period**. This decrease of consumption was assumed to cause a directly proportional reduction on the size of the beef industry in Alberta; it is assumed that diminished North American demand would not be offset by an increase in exports to overseas or emerging markets.

Export values are projected based on the overall industry size with the export values of animals and crops in 2014 [6].

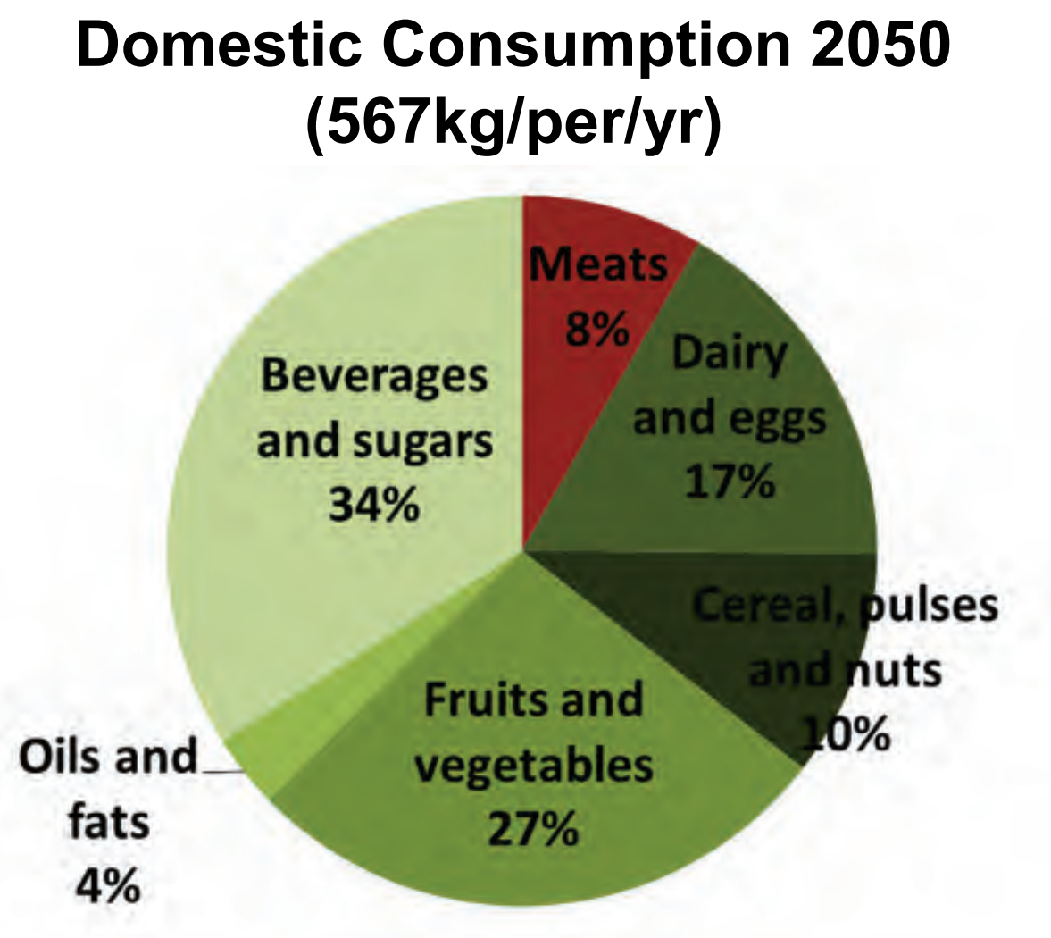
RESULTS & DISCUSSION

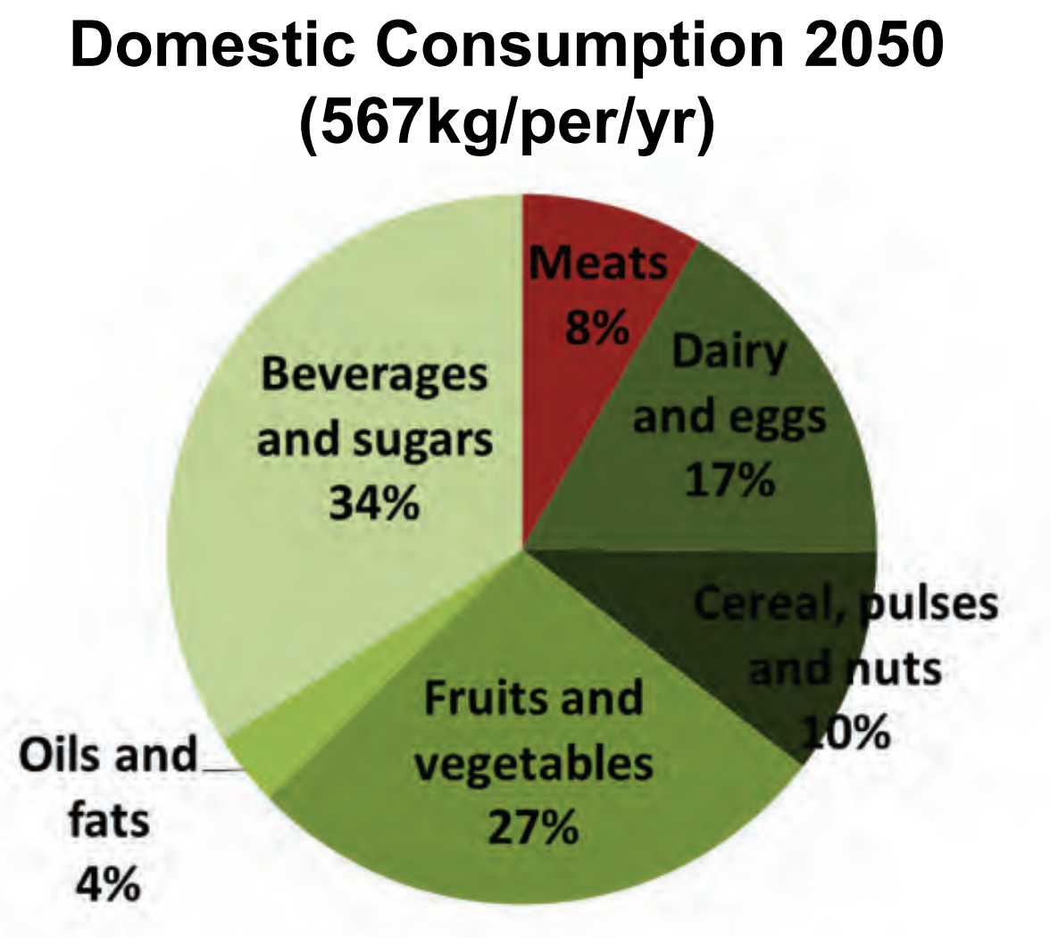
Reference | Scenario 1: Chicken Replacement | Scenario 2: Bean Replacement

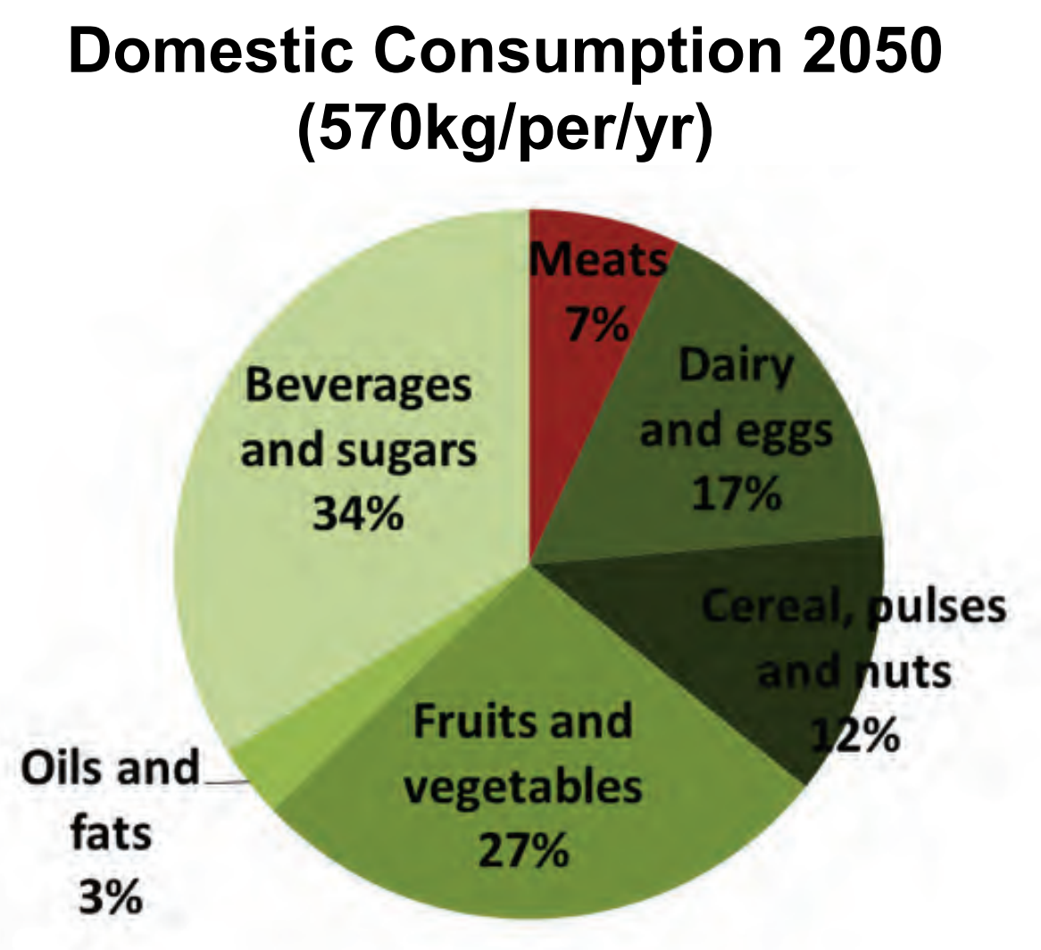
1a. Daily Diet Profile

By 2050:
Scenario 1: 50% beef replaced with chicken

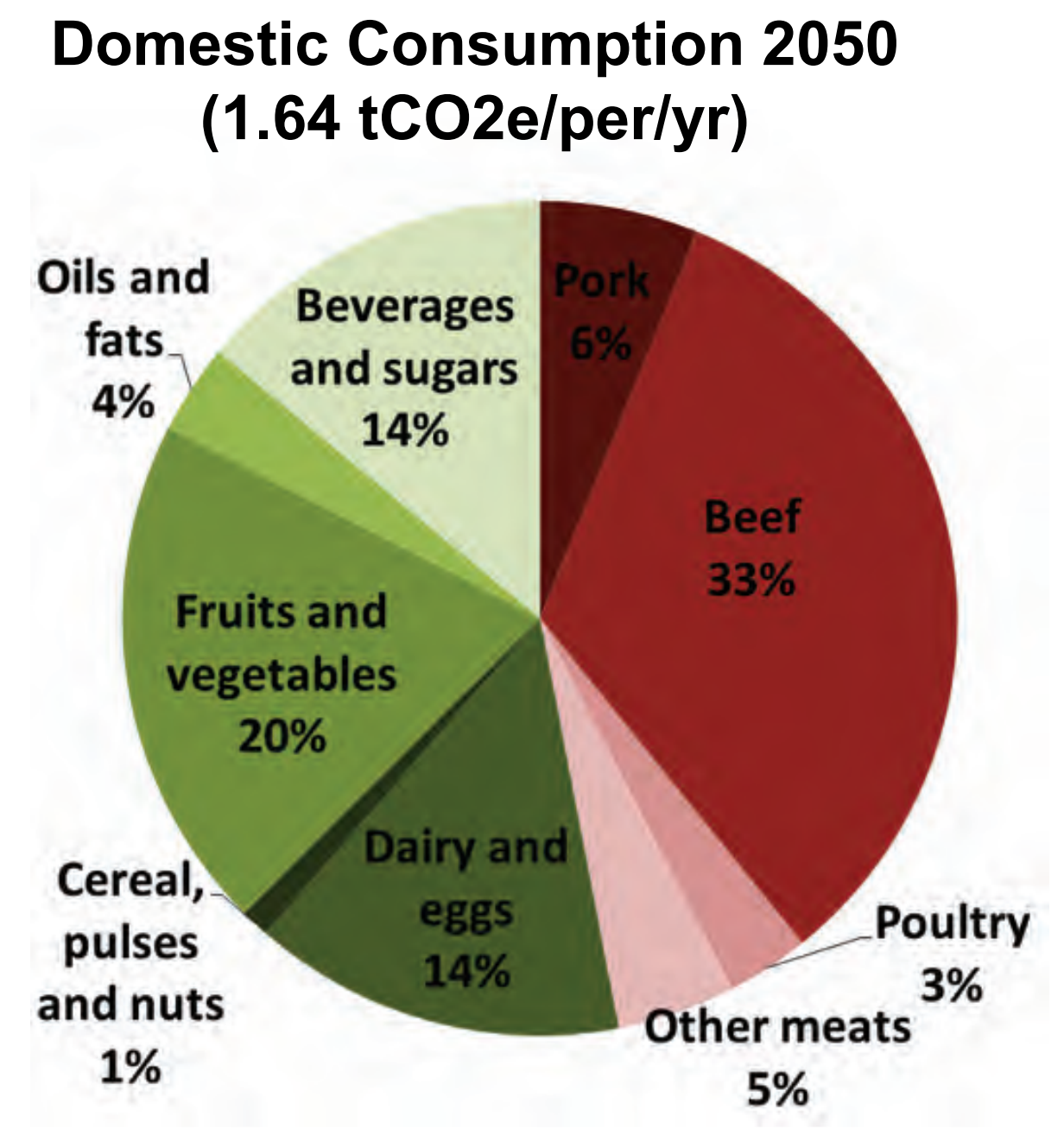
Scenario 2: 50% beef replaced with beans

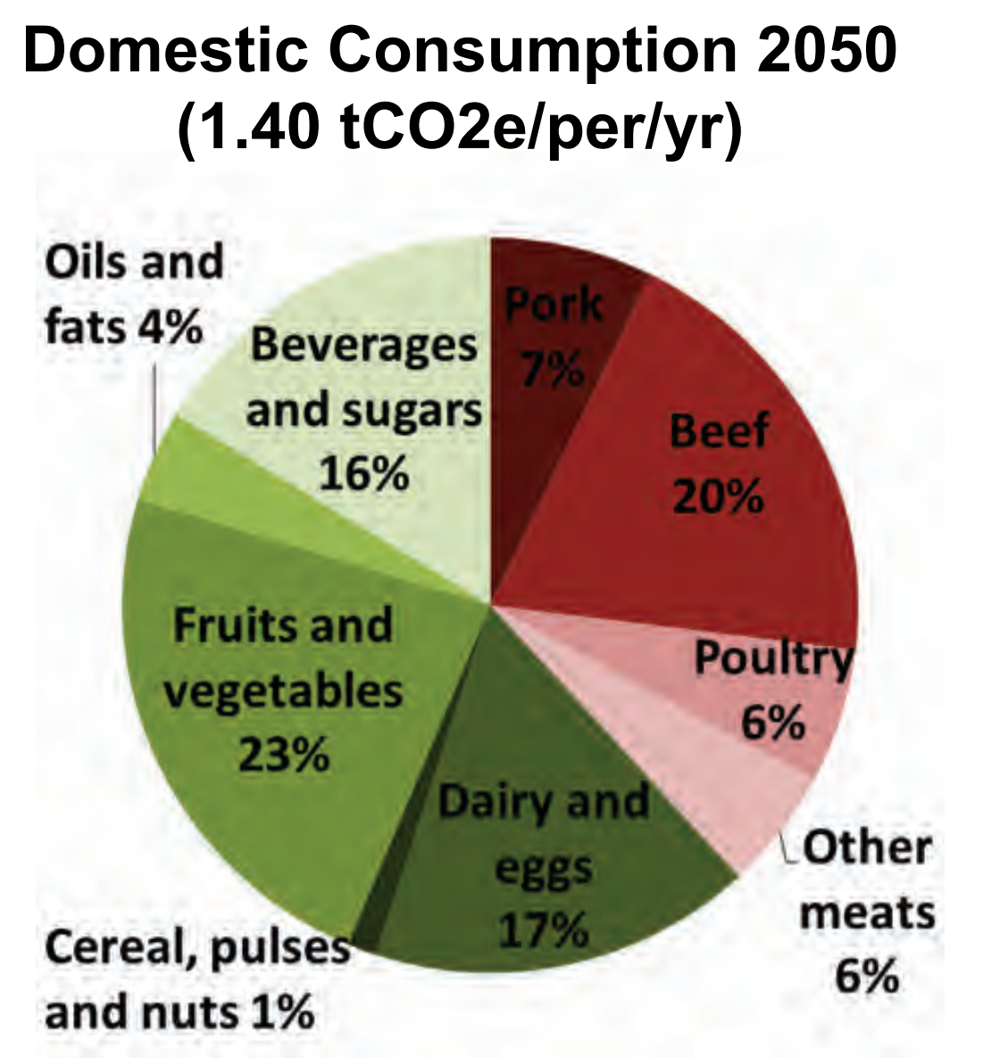


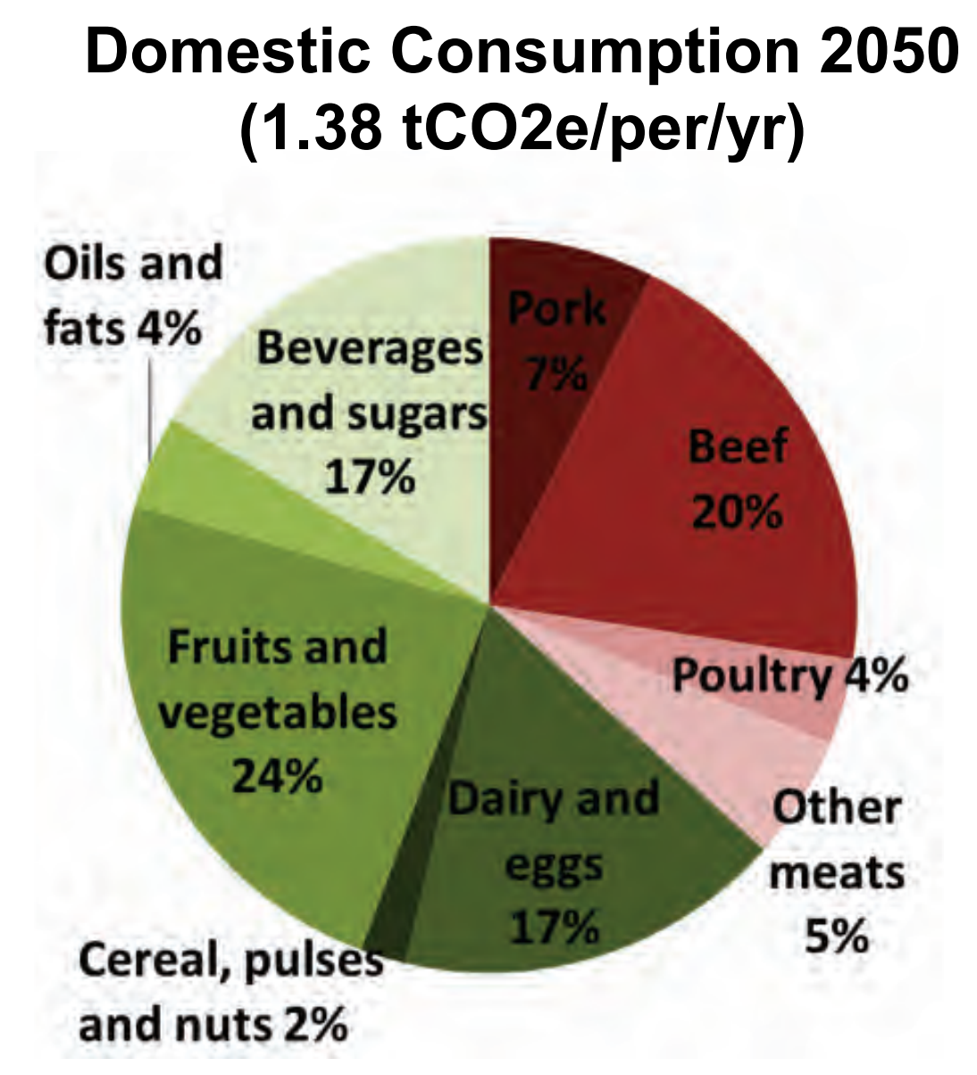




1b. Daily Diet-Related Emissions





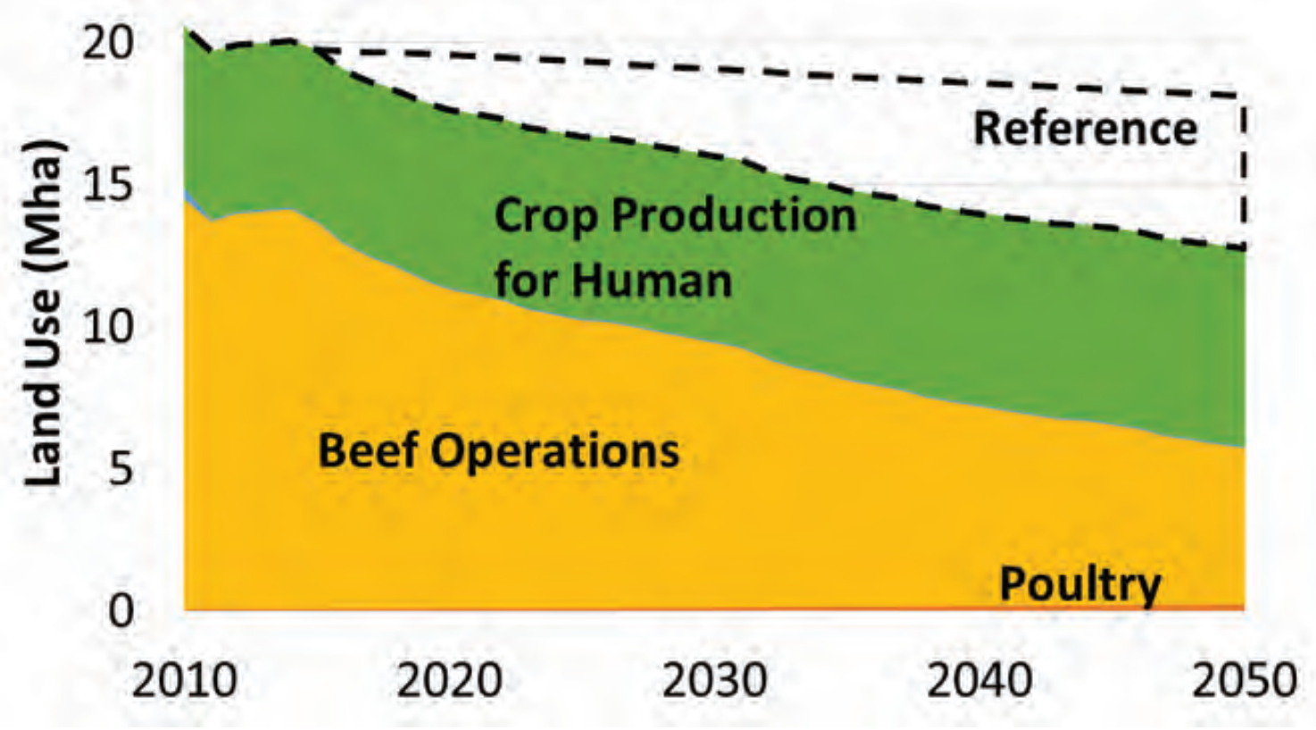


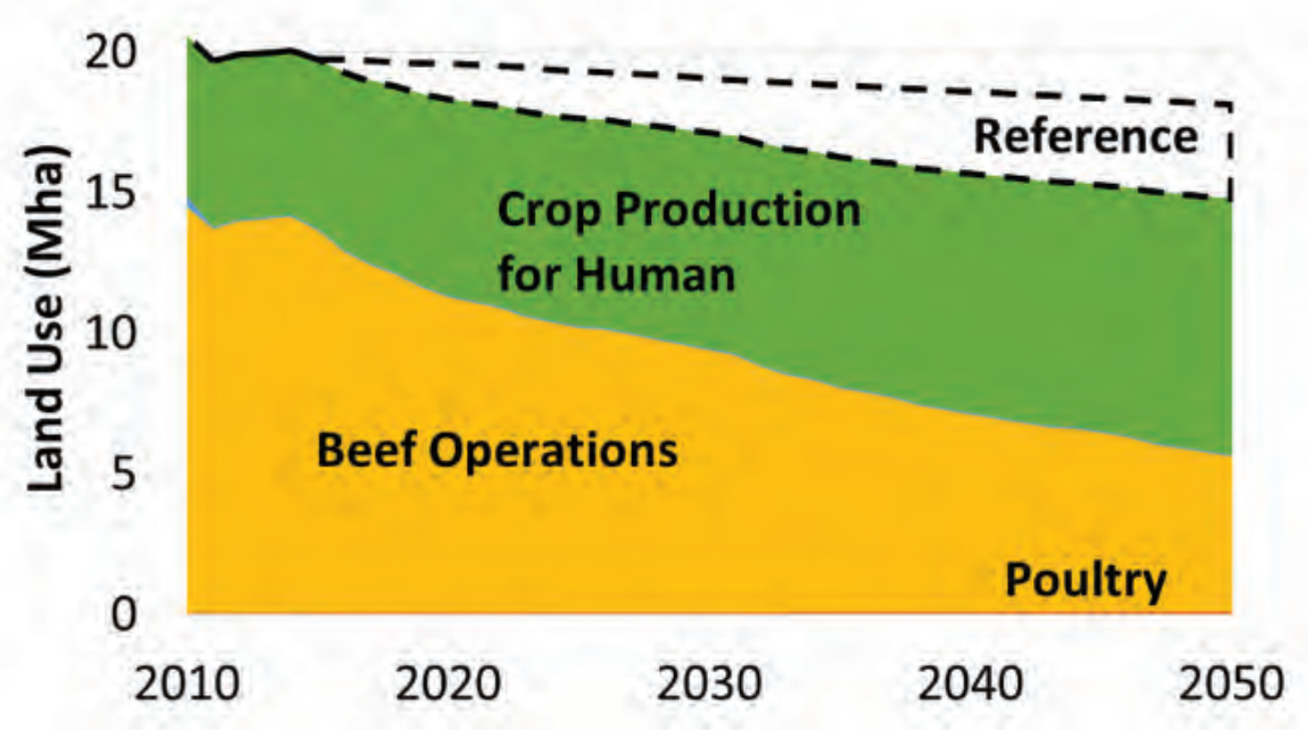
- ➢**0.24 tCO_2e/person/year reduction by 2050**
- ➢**0.26 tCO_2e/person/year reduction by 2050**

Scenario 1: Chicken Replacement | Scenario 2: Bean Replacement

2a. Land Use

Change in land use resulting from dietary changes (Mha) [7]

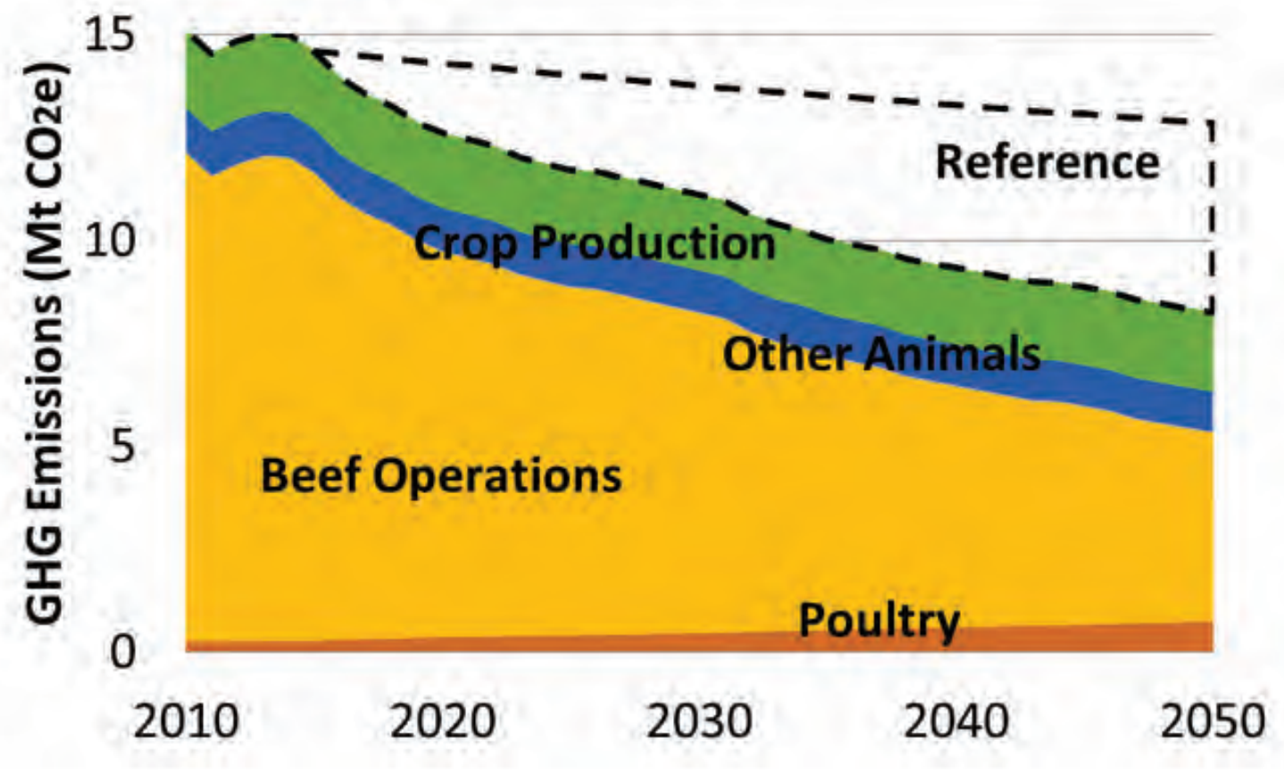


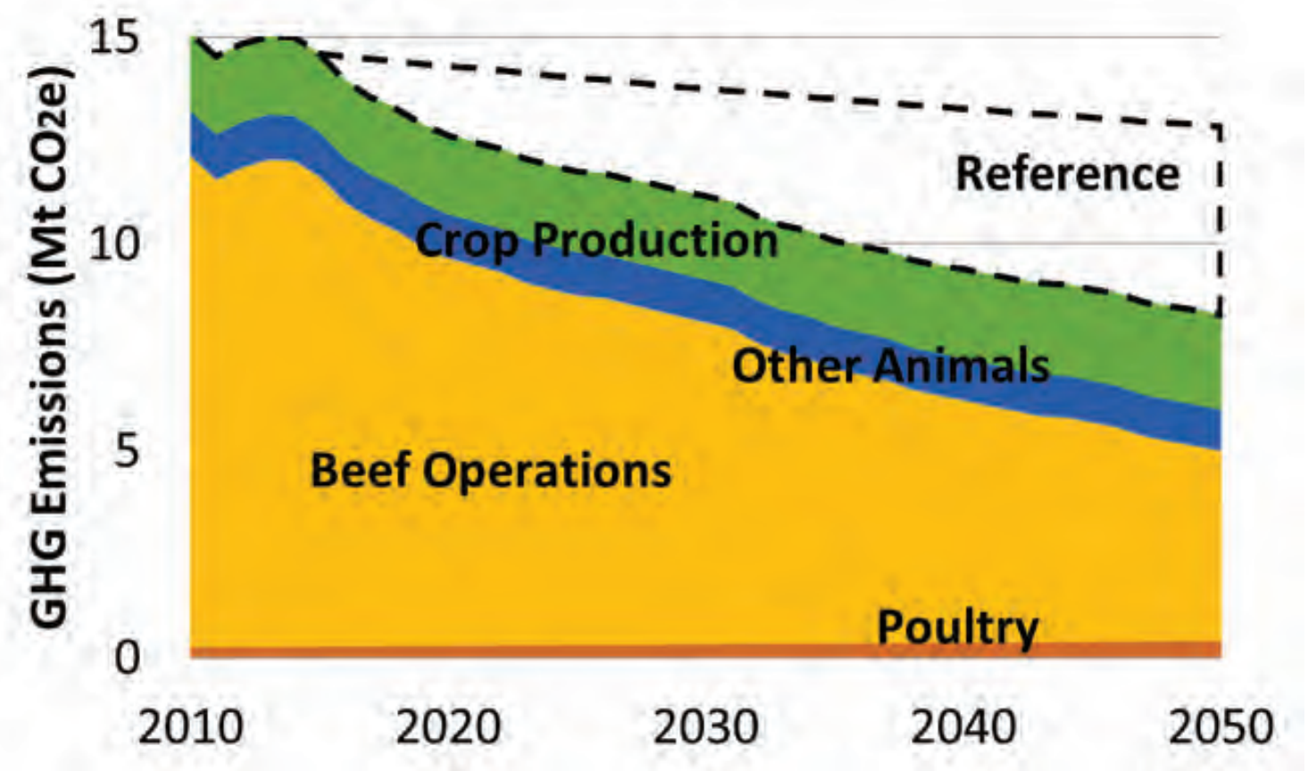


➢**22%** and **18%** total **reduction** in **land used** for Scenario 1 and 2, respectively

2b. Emissions

Change in emission resulting from dietary changes (Mt CO_2e) [5]

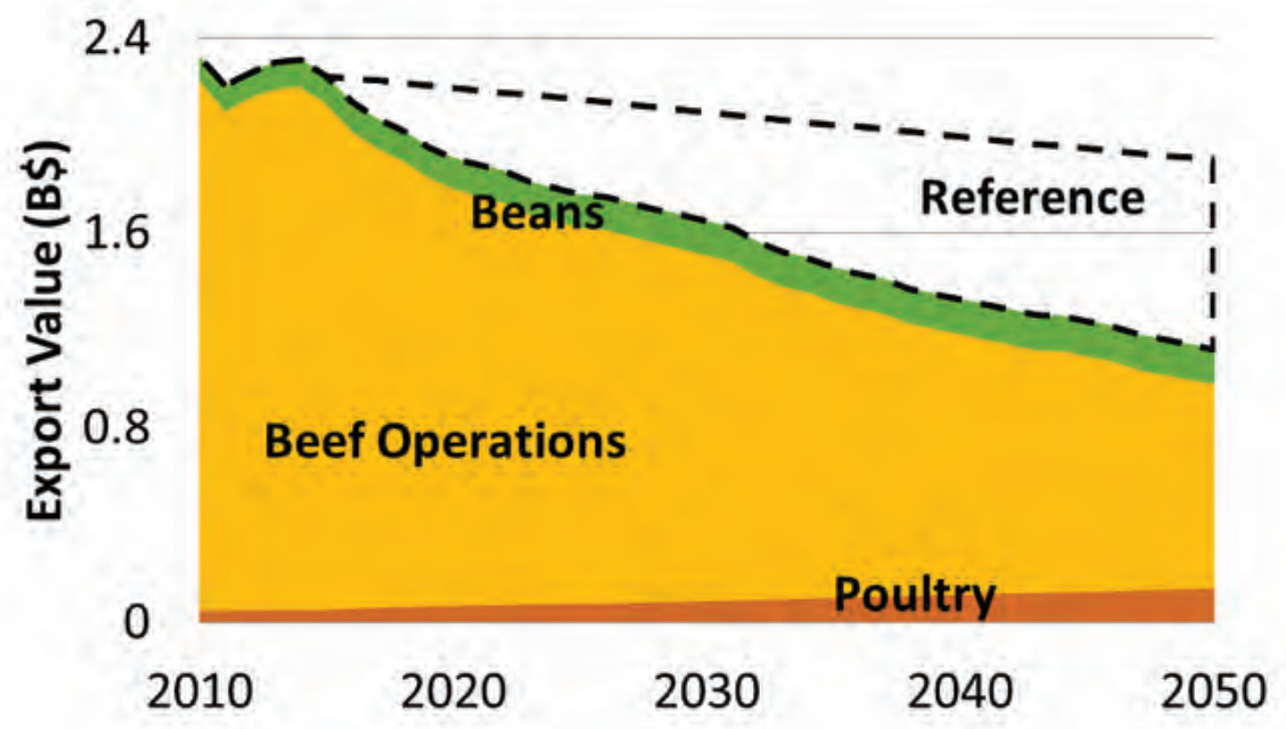


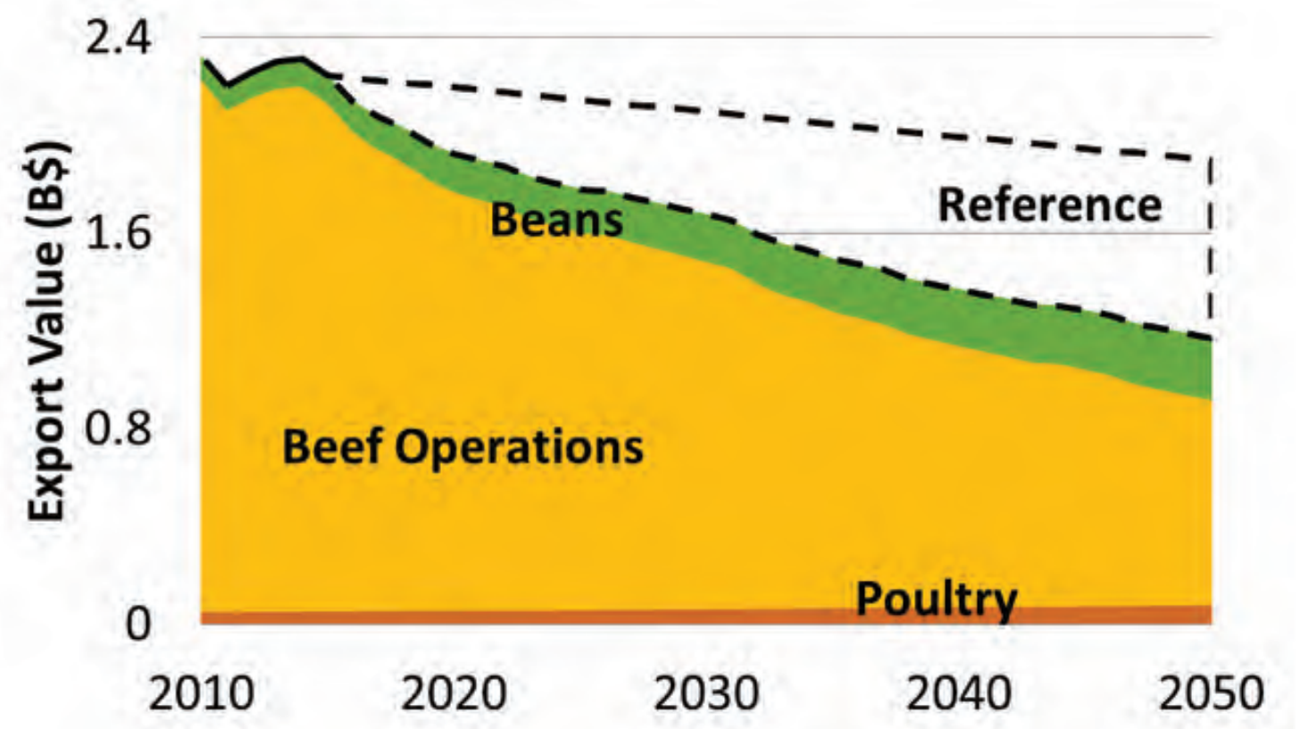


➢**35%** and **34%** total **reduction** in **emission** (CO_2e) for Scenario 1 and 2, respectively

2c. Export Values

Change in export values resulting from dietary changes (B$) [6]





➢**40%** and **39%** total **loss** in **export values** for Scenario 1 and 2, respectively

CONCLUSIONS

The current North American dietary trend away from red meat, towards white meat and plant proteins, result in both health and environmental benefits.

If the dietary trend were to continue so that 50% of present-day beef consumption is replaced by less carbon-intensive protein alternatives (such as chicken and beans), a person's daily protein requirements would still be met. This would result in approximately 4.6 Mt CO_2e per year reduction by 2050.

Land use patterns in Alberta would also change, as land that had previously been used to graze and feed cattle could be used for environmental or economical purposes. This could include planting trees or cash crops.

It can be assumed that the decreased beef demand would proportionally diminish Alberta's cattle industry, since North America is its primary market. A 40% reduction in export values equals to loss of $0.8 billion.

Given that one of the main drivers away from red meats is its associated carbon footprint, Alberta's agricultural industry should look into reducing the emissions associated with cattle. Studies suggest that this can be achieved by feeding cattle higher quality grains [8]. Such initiatives would offset the revenue losses as Albertan beef becomes a more environmentally attractive protein option to North American consumers.

REFERENCES

[1] Statistic Canada (2015). Cattle Inventories. [Online]. Retrieved from: http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/prim50a-eng.htm
[2] Canada Beef (2015). Integrated North American Market. [Online]. Retrieved from: http://www.canadabeef.ca/us/en/import/default.aspx
[3] FCC AG Economics (2015). The 2015 Beef Sector Report. [Online]. Retrieved from: https://www.fcc-fac.ca/fcc/about-fcc/corporate-profile/reports/beef-sector/beef-sector-report-2015.pdf
[4] World Health Organization (2015). Consumption of red meat and processed meat. [Online]. Retrieved from: https://www.iarc.fr/en/media-centre/pr/2015/pdfs/pr240_E.pdf
[5] Holos. (2014, July 15). Retrieved November 16, 2015, from http://www.agr.gc.ca/eng/science-and-innovation/science-publications-and-resources/holos/?id=1349181297838
[6] Government of Alberta. (2014). Agri-Food Exports. [Online]. Retrieved from: http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/sdd15300/$FILE/agrifood_exports_ab_2005-2014_report.pdf
[7] Nijda D., Rood T., Westerhoek H. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy 37 (2012) 760-770
[8] Government of Canada. (2012). Reducing Methane Emissions from Livestock. Retrieved from: http://www.agr.gc.ca/eng/science-and-innovation/science-publications-and-resources/technical-factsheets/archived-content-reducing-methane-emissions-from-livestock/?id=1305058576718

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