BIOMETHANE CAN FUEL NET ZERO CARBON MARITIME

A ***BOUNTY*** FOR GLOBAL FUGITIVE EMISSIONS

Alex MacFarlane, RNG Connect

1. The opportunity and urgency of fugitive emissions
2. Life Cycle Assessment and the potential of E_{sca}
3. How Canada got it right
4. Robust and defensible accreditation
5. Action on LCA

Negative emissions biomethane offers the opportunity to produce more ZNZ Carbon fuel at lower cost/ton of delivered biofuel *while cleaning up the world*.

1 unit of biomethane from organic waste or manure can yield 2x or more units of IMO ZNZ LBM or Biomethanol

RNG Connect

IMO NET ZERO FRAMEWORK (IMONZF) DEMANDS A LARGE SUPPLY OF BIOMASS-BASED RESOURCE

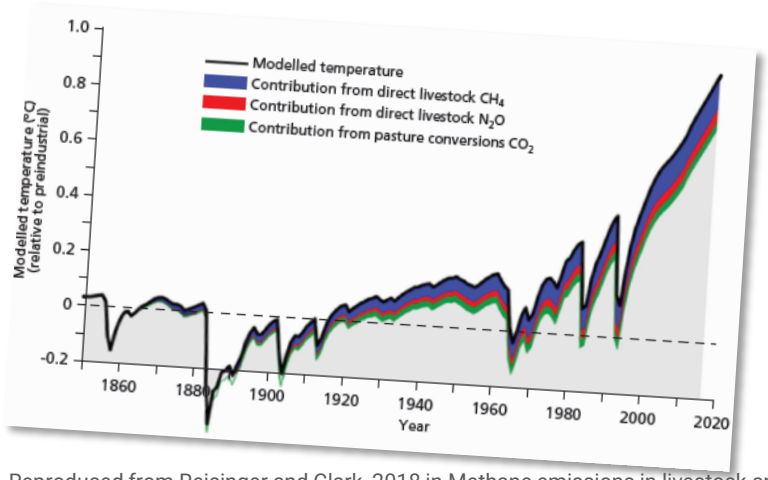
- 8 Etajoules of Shipping Energy Fuel Demand by 2050 in the Net-Zero Emissions scenario, ~200Mtoe or 7.5 Quads*
- 800 Million Tons of CO_2 reduction annual as compared to 2023* - 1x Saudi or Canada
- Waste sources are clearly preferable vs food and feed competitive sources of biofuel

*Calculated from IEA, World Energy Outlook 2024

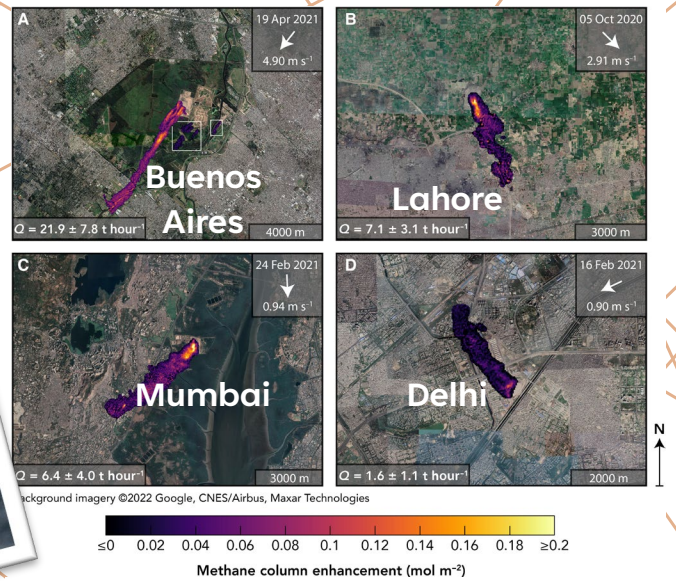
WASTE MANAGEMENT IN CRISIS WORLDWIDE, WHILE METHANE AND N_2O INCREASE UNCONTROLLABLY

Of the observed net increase of 1.1°C in global temperatures… 0.5°C can be attributed to methane (IPCC, 2023b)

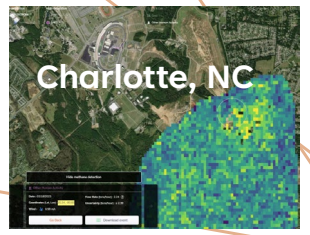
IPCC, 2023b, 'Summary for Policymakers', in: *Climate Change 2021: The Physical Science Basis,* Cambridge University Press, pp. 3-32.

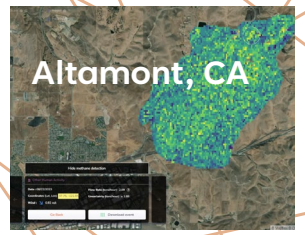


Reproduced from Reisinger and Clark, 2018 in Methane emissions in livestock and rice systems, FAO, 2023



https://www.science.org/doi/full/10.1126/sciadv.abn9683

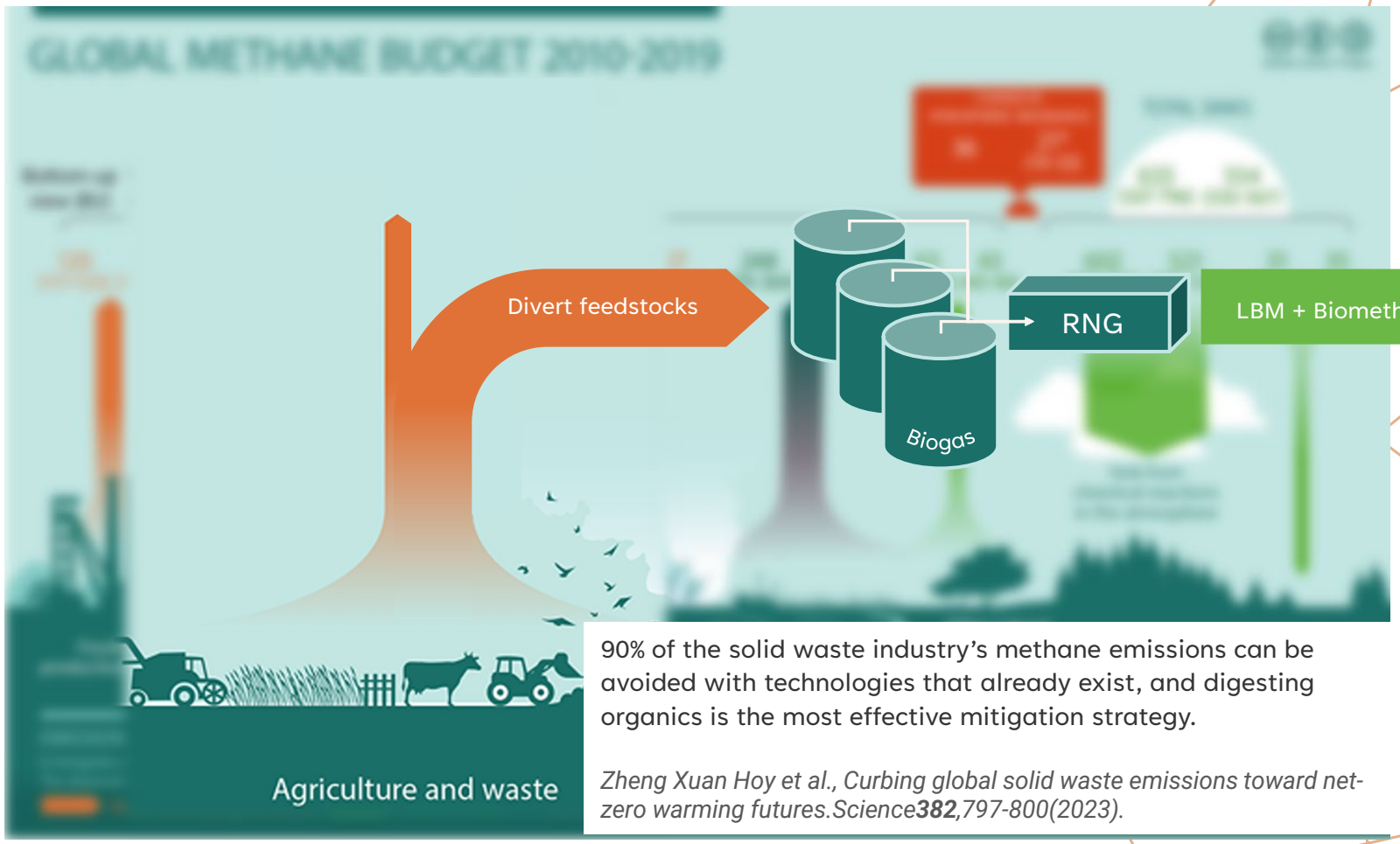




"…another critical lever—municipal solid waste management—has been overlooked despite its potential for rapid impact on reducing carbon emissions and its ability to give more room in the global carbon budget to hard-to-abate sectors…"

Michael E. Webber, Yael R. Glazer, Solid waste, a lever for decarbonization. *Science* **382**,762-763(2023).

WASTE AND AG ARE THE LARGEST ANTHROPOGENIC SOURCES OF METHANE (& N_2O) EMISSIONS, FOLLOWED BY FOSSIL FUEL EXTRACTION AND USE

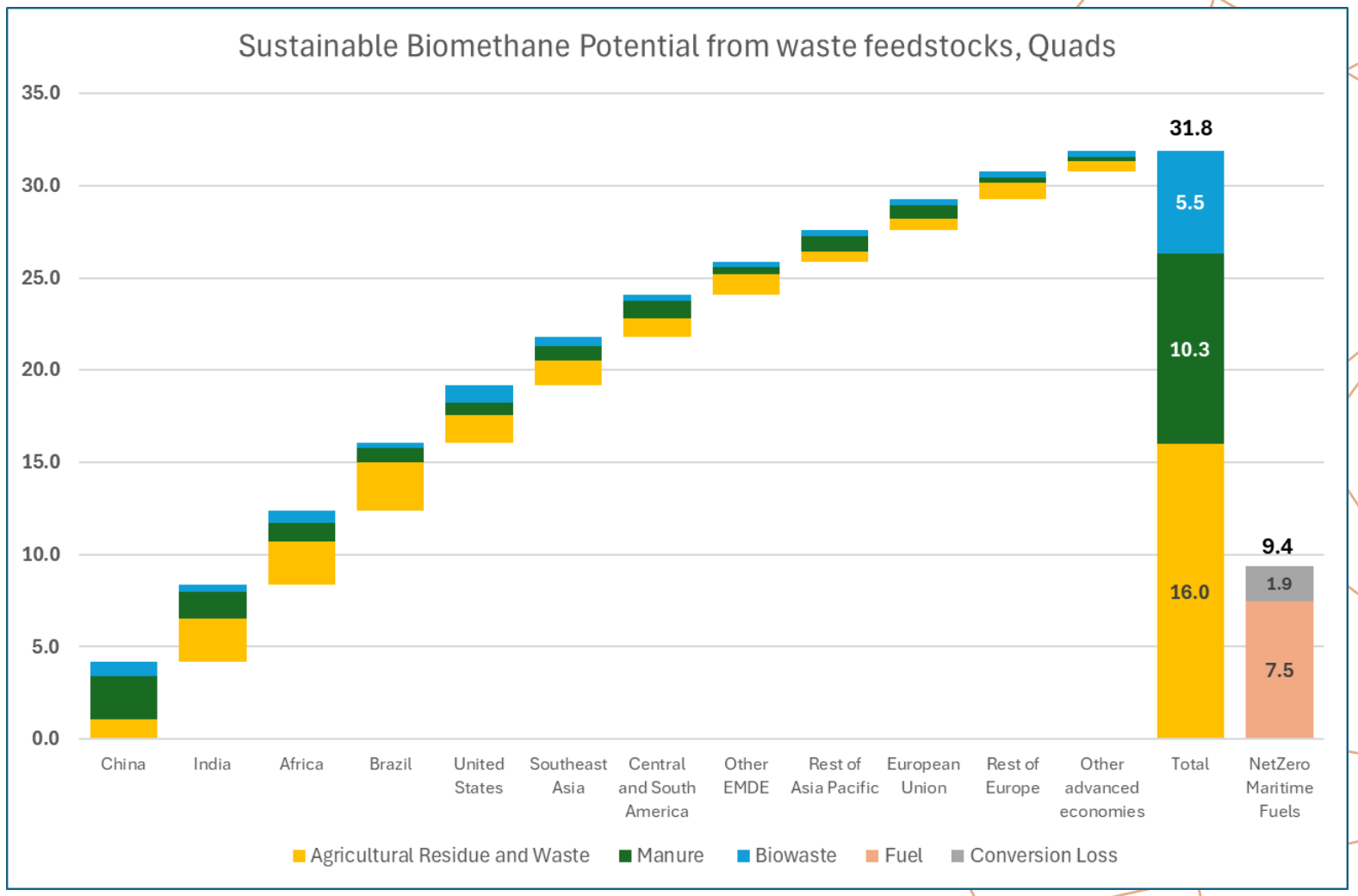


90% of the solid waste industry's methane emissions can be avoided with technologies that already exist, and digesting organics is the most effective mitigation strategy.

*Zheng Xuan Hoy et al., Curbing global solid waste emissions toward net-zero warming futures.Science**382**,797-800(2023).*

M. Saunois et al.: Global Methane Budget 2000–2020

BIOMETHANE FROM WASTE CAN MEET MARITIME ENERGY DEMAND



Calculated from: IEA (2025), Outlook for Biogas and Biomethane, IEA, Paris https://www.iea.org/reports/outlook-for-biogas-and-biomethane, License: CC BY 4.0

BIOMETHANE'S EXTRAORDINARY VALUE REQUIRES IMONZF'S LIFECYCLE ASSESSMENT (LCA) CALC RECOGNITION

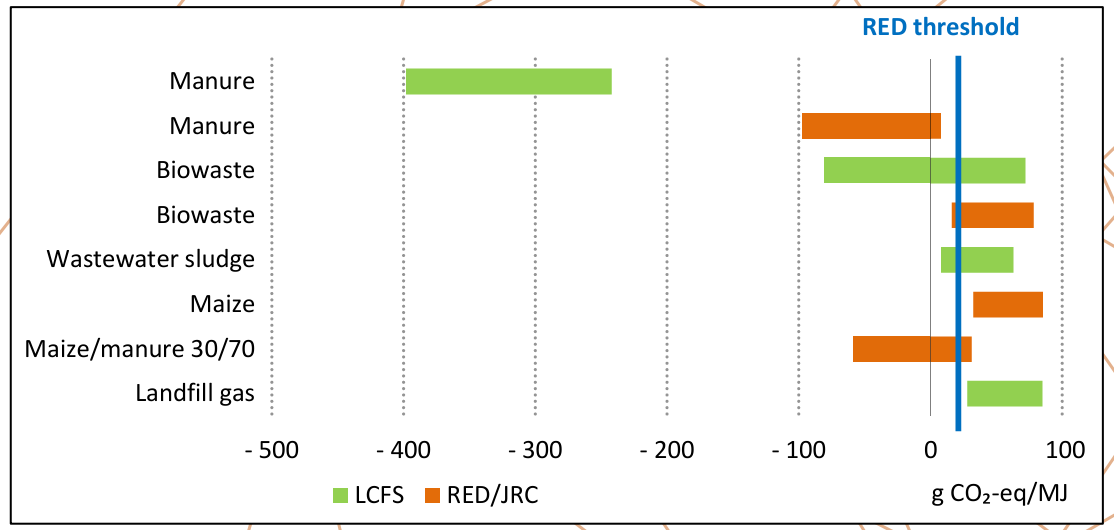
$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr},$$

e_{sca} is "Soil Carbon Accumulation". This is seen as a placeholder value for negative emissions associated with various fuel pathways.

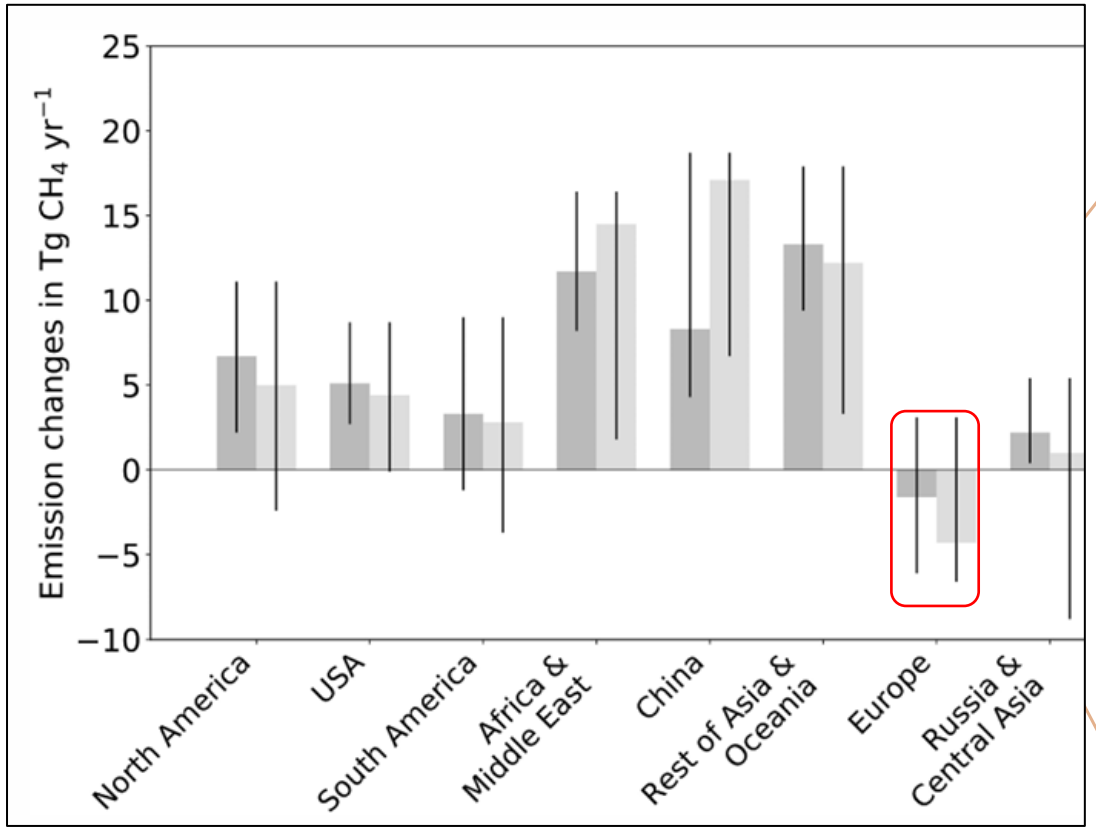
RISK OF INERTIA: IMO LCA MAY NOT PROPERLY ACCREDIT AVOIDED METHANE EMISSIONS FROM BIOWASTE (LIKELY OKAY ON MANURE)

RED II (used for FuelEU) does not recognize negative emissions from biowaste diversion to AD. Does include manure.

- "Biofuels" cannot have negative carbon emissions
- Wastes and residues, including treetops and branches, straw, husks, cobs and nut shells, and residues from processing, including crude glycerine and bagasse, shall be considered to have zero life-cycle greenhouse gas emissions up to the process of **collection**.
- RED II calculation assumes a policy baseline where landfilling of untreated organic waste is being rapidly phased out within the EU due to the Landfill Directive and other waste management regulations.



…AT A REGIONAL LEVEL ONLY EUROPE* REDUCED FUGITIVE METHANE OVER THE LAST 20 YEARS. IF WE WANT TO MAKE A DENT, WE NEED STRONG POLICIES AND INCENTIVES…



R B Jackson et al 2020 Environ. Res. Lett. 15 071002

WE NEED A BOUNTY ON FUGITIVE METHANE!

**Honorable mention to Japan, all-star of organic waste management*

HOW CANADA GOT IT RIGHT IN THE CLEAN FUEL REGULATION (CFR)

Environment and Climate Change Canada ECCC rule-makers were headed down the path of using “strictest regulation” as the baseline

Would have assigned virtually no avoided emissions credits to organics diversion because Nova Scotia has a 100% composting law

But…

Stakeholders encouraged ECCC to look at the Canada-wide reality with respect to organics diversion and landfill methane capture.

ECCC found **77% of food waste** and 32% of yard and garden goes in the landfill and **64%(!) of resulting landfill methane escapes.**

ECCC expanded the system boundary to consider emissions differential upstream of collection.
(I would argue not upstream of collection, but rather a negative emission produced by collection)

ROBUST AND DEFENSIBLE AVOIDED EMISSIONS VALUES

- Must avoid double-counting.

Emissions credits are sold ONCE with the fuel. Share/allocation of these credits to host-nation NDCs is an important discussion (in which polluter pays principle should prevail (IMHO)).

- Comply with principles of additionality by using regional current data. Remember strict regulations do not equal compliance.

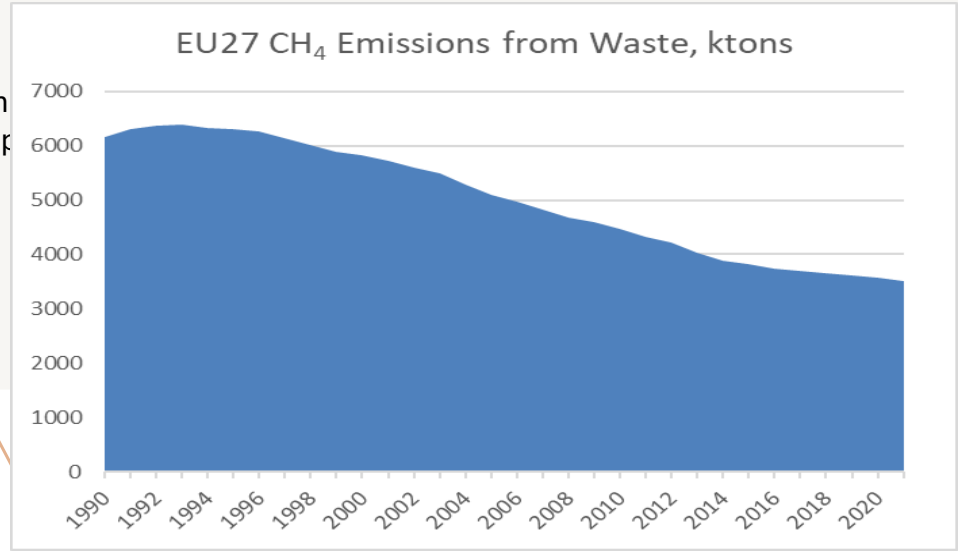
"If an alternative scenario does not comply with all mandatory applicable legislation and regulations, then show that, based on an examination of current practice in the country or region in which the mandatory law or regulation applies, those **applicable mandatory legal or regulatory requirements are systematically not enforced and that non-compliance with those requirements is widespread** in the country. If this cannot be shown, then **eliminate the alternative scenario** from further consideration." *UNFCCC, Clean Development Mechanism, "Combined tool to identify the baseline scenario and demonstrate additionality", paragraph 17. https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-02-v7.0.pdf*

- Create a mechanism to decrease the baseline emissions values as

Waste diversion and recycling rate data are widely available and inventories are conducted on
Combined with satellite inventories, we can **track improvement over time and adjust** these p

- RIGOROUS biomethane supply chain fugitive CH_4 capture

We have all the tools to keep total biomethane loss below 1% into the pipelines



https://rt.unfccc.int/locator

REVIEW, CALL TO ACTION

- Marine fuel is massive potential new demand sink for biomethane
- Waste feedstocks can meet the entire demand on an energy basis, while offering even larger carbon reductions.
- IMO has an opportunity to recognize and reverse the enormous damage caused by non-CO2 GHGs in ag and waste sectors.
- Get the right value for e_{sca}
- Work with official IMO Consultative Status orgs to provide data for the LCA processes.
- Stay in touch!

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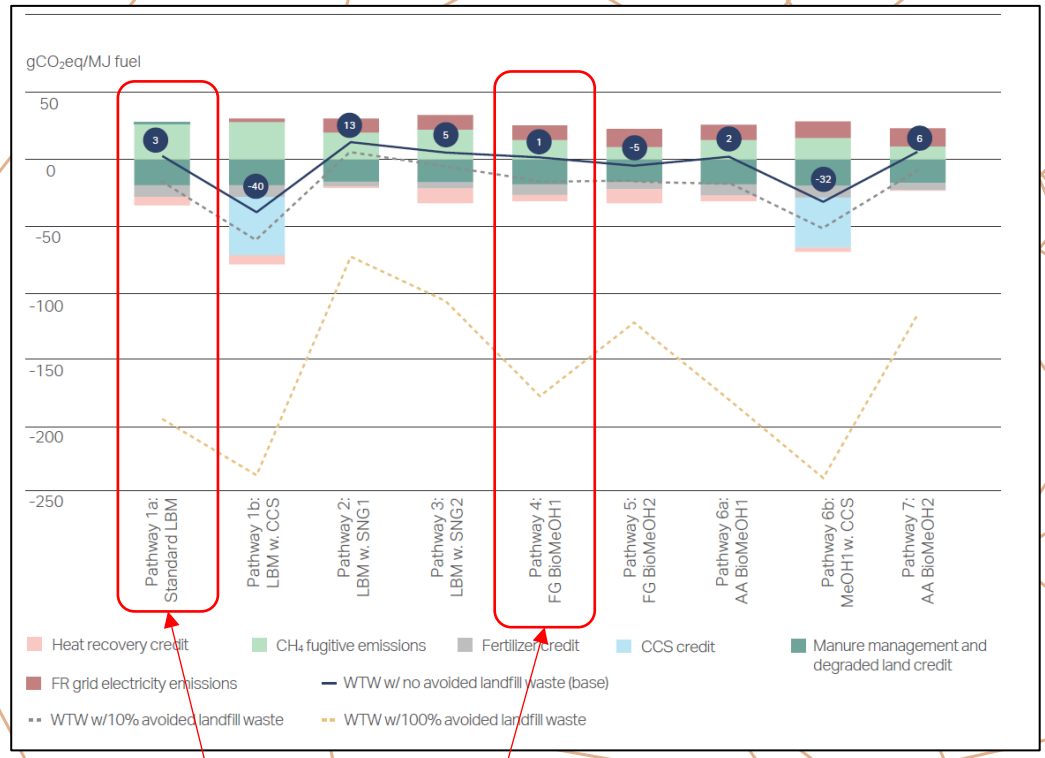
Over 20 years of experience leading project development and financing of transformative clean energy projects, especially the biogas sector. He has coordinated activities across technical, legal, commercial, and operational areas.

IMONZF SCHEDULE AND LCA

Adoption, Implementation

Milestone	Date/Timeframe
Approval	April 2025 (MEPC 83) ☑
Formal Adoption	October 2025
Guidelines Finalized	Spring 2026
Entry into Force	2027
First Compliance	2028

- Life Cycle Assessment Working Group busy through 2025 (met some weeks back)
- LCA Guidelines approved in April pay special attention to shore power, methane slip from LBM engines and Land-Use changes of biofuels
- "Biowaste" not CI-negative by default, but IMONZF ***should*** allow actual life cycle emissions, subject to rigorous LCA.



Liquified biomethane (-190) and biomethanol (-175) from 100% LF diversion
from, Zero Carbon Shipping

USING ECCC CFR'S LANDFILL METHANE EMISSIONS BASELINE

1

- Parameters for DOC and DOC_f were set in dry weight instead of wet weight.
- Equation A3.6-2 $DDOC_m = Waste\ deposited_m \times DOC_m \times DOC_{fm}$

$DDOC_m$	mass of decomposable degradable organic carbon from material m that is deposited (tonne)
$Waste\ disposed_m$	mass (dry) of waste material m deposited
DOC_m	fraction of degradable organic carbon (dry) in waste type m
$DOC_{f,m}$	fraction of DOC that can/does decompose, for waste type m
m	type of waste material type deposited (e.g., food, paper, etc.).

DOC (dry): 2006 IPCC, Vol 5, Ch. 2, Table 2.4
DOC_f: 2019 Refinement to 2006 IPCC, Volume 5, Chapter 3, Table 3.0

m	DOC (dry)	DOC_f
Food	0.38	0.7
Yard & Garden	0.49	0.7

2

$$CH_4 generated = DDOC_m \times FracCH4 \times 16/12 \times MCF$$

CH_4 generated	amount of CH_4 generated from decomposable material
DDOCm	DDOCm (decomposable degradable organic carbon, from waste material m) that decomposed in the landfill (tonne)
FracCH4	fraction of CH4, by volume, in landfill gas
16/12	molecular weight ratio CH_4/C
MCF	methane correction factor

Section A3.6.1.2.1, 2023 NIR	
FracCH4	0.5
MCF	1.0

3

$$CH_4 emitted = CH_4 generated \times (1 - NLGR) \times (1 - OX) + CH_4 flared \times (1 - Efcy_{flr})$$

Where $CH_4 flared = CH_4 generated$

$CH_4 emitted$	CH_4 emitted from landfills (tonne)
CH_4 generated	CH_4 generated by landfilled waste (tonne)
OX	oxidation factor (fraction)
CH_4 Flared	amount of CH_4 flared (tonne)
NLGR	national landfill gas recovery (%)
$Efcy_{flr}$	flaring efficiency (fraction)

Section A3.6.1.2.1, 2023 NIR	
$Efcy_{flr}$	99.7%
OX	0.1

Calculated with data from Table A3.6-6 in 2023 NIR	
National Landfill Gas Recovery	36%

4

Proposed. Use national or regional level recycling, current diversion and composting rates for each material to determine baseline landfilling rate and resulting emissions per dry ton (~probability of fugitive methane from each feedstock)

CH4 EMISSIONS FROM WASTE FEEDSTOCKS IN CANADA, IN CONSIDERATION OF CURRENT RECYCLING AND DIVERSION RATES

Landfilled in Canada

Waste Type	Wet Tons*	Moisture	Dry Tons	DOC	DOCf	DDOCm	CH4 Generated	CH_4 Tons Emitted, Calculated Herein	CO2e (GWP 28)	Quantity Recycled, Composted	CO2e Avoided Emissions per dry ton of feed
Food	5,802,000	75%	1,450,500	0.38	0.7	385,833	257,222	148,438	4,156,255	23%	2.21
Paper	2,752,000	20%	2,201,600	0.44	0.5	484,352	322,901	186,340	5,217,517	75%	0.59
Wood	2,461,000	60%	984,400	0.50	0.1	49,220	32,813	18,936	530,206	20%	0.43
Yard/Garden	1,092,000	60%	436,800	0.49	0.5	107,016	71,344	41,171	1,152,793	68%	0.84
Pet Waste	802,000	85%	120,300	0.40	0.7	33,684	22,456	12,959	362,849	0%	3.02
Diapers	714,000	60%	285,600	0.60	0.5	85,680	57,120	32,963	922,959	5%	3.07
Textiles	347,000	15%	294,950	0.30	0.5	44,243	29,495	17,021	476,587	15%	1.37
Rubber (not inc. tires) / Leather	331,000	14%	284,660	0.47	0.1	13,379	8,919	5,147	144,121	0%	0.51
Other (degr.)	1,644,000	67%	542,520	0.45	0.5	122,067	81,378	46,962	1,314,925	30%	1.70
Total	**15,945,000**		**8,385,500**					**509,936**	**14,278,213**		

Note the total CO2e from waste management calculated herein excludes biosolids, and other organic waste streams.
Baseline emissions associated with Composting of diverted materials also excluded (would increase emissions of baseline)

Tons CH4 from waste management in Canada, comparison:

landfills only:	**585,510**	landfills only, https://wastemap.earth/map?mode=country&country=CAN
all waste	**768,040**	All wastewater, composting, landfills, incinerators IPCC, https://rt.unfccc.int/locator
all waste	**816,690**	IEA; Average based on United Nations Framework Convention on Climate Change (UNFCCC) (2022), Greenhouse Gas Data Interface, available at: https://di.unfccc.int/; O'Rourke, P. R, Smith, S. J., Mott, A., Ahsan, H., McDuffie, E. E., Crippa, M., Klimont, S., McDonald, B., Z., Wang, Nicholson, M. B, Feng, L., and Hoesly, R. M. (2021, February 05). Community Emissions Data System (CEDS) v-2021-02-05 Emission Data 1975-2019 (Version Feb-05-2021). Available at: http://doi.org/10.5281/zenodo.4509372.; Crippa, M., Guizzardi, D., Solazzo, E., Muntean, M., Schaaf, E., Monforti-Ferrario, F., Banja, M., Olivier, J.G.J., Grassi, G., Rossi, S., Vignati, E. (2021), GHG emissions of all world countries - 2021 Report, EUR 30831 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-41547-3, doi:10.2760/173513, JRC126363; (2022) EDGAR - Emissions Database for Global Atmospheric Research (EDGAR) v7.0 Greenhouse Gas Emissions. European Commission, Joint Research Centre (JRC) [Dataset] PID: https://edgar.jrc.ec.europa.eu/dataset_ghg70; Climate Watch (2022), Food and Agriculture Organisation of the United Nations (2022). Climate Watch data: Climate Watch, 2022, GHG Emissions, Washington, DC: World Resources Institute. FAO 2022, FAOSTAT Emissions Database. Available at: https://www.climatewatchdata.org/ghg-emissions

Fraction CH4	0.50
MCF	1.00
NLGR	0.36
Flare Efficiency	1.00
Oxidation	0.10

EXAMPLE CALCULATION OF E_{SCA} AT CANADIAN NATIONAL SCALE

100 tons of organic fraction containing nationally representative materials, destined to landfill diverted to AD for energy production, using same conversion indices

Waste Type	Wet Tons	Moisture	Dry Tons	DOC	DOCf	DDOCm	CH4 Generated(tons)	Energy Content (GJ, LCV)	CO2e Avoided Emissions per dry ton of feed	Canadian Feedstock E_{sca} (gCO2e/MJ)
Food	36.39	75%	9	0.38	0.70	2.42	1.61	81	2.21	249
Paper	17.26	20%	14	0.44	0.50	3.04	2.03	101	0.59	81
Wood	15.43	60%	6	0.50	0.10	0.31	0.21	10	0.43	259
Yard/Garden	6.85	60%	3	0.49	0.50	0.67	0.45	22	0.84	103
Pet Waste	5.03	85%	1	0.40	0.70	0.21	0.14	7	3.02	323
Diapers	4.48	60%	2	0.60	0.50	0.54	0.36	18	3.07	307
Textiles	2.18	15%	2	0.30	0.50	0.28	0.18	9	1.37	275
Rubber/Leather	2.08	14%	2	0.47	0.10	0.08	0.06	3	0.51	323
Other (degr.)	10.31	67%	3	0.45	0.50	0.77	0.51	26	1.70	226

REFERENCE CALCS, CANADIAN ESCA

Moisture Content References

Material	Moisture Content (%)	Value used	Source (1)	Web Address (1)	Source (2)	Web Address (2)
Food	60-80%	75%	ECCC Technical Document on MSW Organics Processing	https://www.canada.ca/content/dam/eccc/migration/main/gdd-mw/3e8cf6c7-f214-4ba2-a1a3-163978ee9d6e/13-047-id-458-pdf_accessible_ang_r2-reduced-20size.pdf	Dryclone Recycling Product News	https://www.recyclingproductnews.com/article/28724/the-dryclone-air-drying-system-provides-energy-efficient-way-to-decrease-moisture-in-food-waste
Paper	5-20%	20%	USDA Decomposition of forest products in landfills	https://www.fpl.fs.usda.gov/documnts/pdf1997/mical97a.pdf	Milestone Study ECCC/CEC	https://www.cec.org/wp-content/uploads/Paper_-Full-Study.pdf
Wood	20-60% (fresh/landfilled wood)	60%	Natural Resources Canada (Firewood)	https://natural-resources.canada.ca/sites/nrcan/files/NRCAN_BB_no7_e_indd.pdf	ComProTec Canada	https://www.comproteccanada.com/moisture.htm
Yard/Garden	50-60% (compost optimal)	60%	AB Leaf & Yard Waste Composting Manual	https://open.alberta.ca/dataset/21b95cfd-25b3-45e5-8b78-7d60020cf713/resource/2a4b4bcb-f68a-4c43-a16e-753ceddd440f/download/1999-leafyardwastecompostingmanual-dec1999.pdf	CCME Compost Guidelines	https://ccme.ca/en/res/compostgdlns_1340_e.pdf
Pet Waste	55-85% (composted, high end)	85%	Dalhousie Dog Waste Compost Study	http://whitelab.biology.dal.ca/in/PDFs/dog_waste_final.pdf		
Diapers	50-60% (wet, waste stream)	60%	No direct official; based on absorbent core data and compost studies	https://www.royale.ca/diapers?bvstate=pg%3A2%2Fct%3Ar		
Textiles	7-15% (cotton, wool, typical)	15%	CAN/CGSB-4.2 Canadian Standard (moisture regain table)	https://publications.gc.ca/site/eng/9.837517/publication.html	CCI Canada - Caring for Textiles	https://www.canada.ca/en/conservation-institute/services/conservation-preservation-publications/canadian-conservation-institute-notes/textiles-environment.html
Rubber/Leather	8-14% (air-dry)	14%	CCI Canada - Caring for Leather	https://www.canada.ca/en/conservation-institute/services/preventive-conservation/guidelines-collections/caring-leather-skin-fur.html		
Other (degr.)	45-67% (biodegradables, compost input)	67%	ScienceDirect (biodegradable MSW frac.)	https://pmc.ncbi.nlm.nih.gov/articles/PMC6277346/		

Recycling and Diversion Rates in Canada

Waste Category	Fraction Recycled (%)	Value used	Source (1)	Web Address (1)	Source (2)	Web Address (2)
Food (Organics)	0.23	23%	ECCC		StatCan (2021 composting)	https://www150.statcan.gc.ca/n1/daily-quotidien/240408/dq240408b-eng.htm
Paper/Cardboard	70-80% (highest of all materials)	75%	Recycling Today & StatCan	https://www.recyclingtoday.org/blogs/news/recycling-in-canada-trends-challenges-and-the-future	Recycling Product News	https://www.recyclingproductnews.com/article/41740/new-data-shows-paper-represents-majority-of-diverted-materials-in-canada
Wood	~15-20% (C&D sector; <10% MSW)	20%	NRCan & RPN (estimates)	https://www.recyclingproductnews.com/article/27965/canadian-wood-recycling-sector-positions-itself-for-growth	NZWC Circular Solutions	https://nzwc.ca/Documents/circular-solutions-wood-waste-final-report.pdf
Yard/Garden	0.68	68%	ECCC		StatCan (2021 composting)	https://www150.statcan.gc.ca/n1/daily-quotidien/240408/dq240408b-eng.htm
Pet Waste	Negligible; only pilot municipal programs	0	Dalhousie Compost Study	http://whitelab.biology.dal.ca/in/PDFs/dog_waste_final.pdf	-	-
Diapers	Negligible (<1% of cities, pilot level only)	5%	Hygienic Material	https://www.hygienicmaterial.com/news/the-number-of-cities-in-canada-that-recycle-di-23543914.html	Nest & Sprout	https://nestandsprout.ca/blogs/cloth-diapers/manufacturing-disposable-diapers
Textiles	<15% (capture rate; remainder landfilled/exported)	15%	NACTR Textile Diversion Report	https://nactr.ca/wp-content/uploads/2022/02/The-Canadian-Textile-Diversion-Industry-April-2019.pdf	RPN 2024/Fashion Takes Action	https://www.recyclingproductnews.com/article/43033/the-canadian-circular-textiles-consortium-receives-federal-funding-to-reduce-textile-and-plastic-waste
Rubber/Leather	Negligible except tires (~18% overall, mostly auto tires)	0%	US EPA Rubber/Leather Data	https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/rubber-and-leather-material-specific-data	-	-
Other (degradable)	Included in organics; likely <30% diverted/recycled	30%	Klean Industries	https://kleanindustries.com/insights/market-analysis-reports/recycling-statistics-in-canada/	StatCan MSW Diverted	https://www150.statcan.gc.ca/n1/daily-quotidien/240408/dq240408b-eng.htm

TABLE 3.0 (NEW)
FRACTION OF DEGRADABLE ORGANIC CARBON WHICH DECOMPOSES (DOC_f) FOR DIFFERENT WASTE TYPES

Type of Waste	Recommended Default DOC_f Values	Remark
Less decomposable wastes e.g. wood, engineered wood products, tree branches (wood)	0.1	An average value of 0.088 was derived from DOC_f values for engineered wood products, sawn woods, tree branches reported in 3 references[1-3]
Moderately decomposable wastes e.g. paper, textile, nappies	0.5	An average value of 0.523 was derived from DOC_f values for paper products, textile and nappies reported in 4 references[4-7].
Highly decomposable wastes, e.g. food wastes, grasses (garden and park waste excluding tree branches)	0.7	An average value of 0.706 was derived from DOC_f values for food wastes and grasses reported in 3 references[4-6]
Bulk waste*	0.5	

[1] Wang *et al.* (2011); [2]Wang and Barlaz (2016); [3] Ximenes *et al.* (2018); [4]Eleazer *et al.* (1997); [5]Bayard *et al.* (2017); [6]Jeong (2016); [7]Wang *et al.* (2015)
* It is used when the fractions of less, moderately and highly decomposable wastes in MSW are not known.

SHIPPING CO_2

Table A.4a: World CO_2 emissions

				Stated Policies (Mt CO_2)				CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2030	2050
Total CO_2*	32 805	37 230	37 723	36 170	33 285	31 185	28 636	-0.6	-1.0
Combustion activities (+)	30 566	34 290	34 789	33 232	30 292	28 163	25 617	-0.7	-1.1
Coal	13 840	15 285	15 667	13 797	11 473	9 974	8 055	-1.8	-2.4
Oil	10 479	11 219	11 334	11 239	10 679	10 123	9 593	-0.1	-0.6
Natural gas	6 062	7 516	7 520	7 945	7 904	7 830	7 737	0.8	0.1
Bioenergy and waste	186	270	267	251	236	236	231	-0.9	-0.5
Other removals** (-)	-	1	1	20	23	27	45	47	14
Biofuels production	-	1	1	1	1	1	1	0.0	0.0
Direct air capture	-	-	0	19	21	26	44	194	36
Electricity and heat sectors	12 513	14 943	15 262	13 311	10 968	9 469	7 757	-1.9	-2.5
Coal	8 952	10 944	11 269	9 607	7 460	6 134	4 583	-2.3	-3.3
Oil	826	677	638	333	262	199	117	-8.9	-6.1
Natural gas	2 621	3 177	3 211	3 239	3 126	3 012	2 929	0.1	-0.3
Bioenergy and waste	115	146	144	131	120	124	128	-1.3	-0.4
Other energy sector**	1 441	1 616	1 579	1 585	1 567	1 539	1 490	0.1	-0.2
Final consumption**	18 590	20 410	20 604	21 106	20 601	20 043	19 288	0.3	-0.2
Coal	4 686	4 243	4 302	4 096	3 927	3 760	3 400	-0.7	-0.9
Oil	9 020	9 909	10 108	10 359	9 893	9 421	9 008	0.4	-0.4
Natural gas	2 854	3 559	3 521	3 888	3 952	3 995	3 991	1.4	0.5
Bioenergy and waste	71	123	124	120	116	112	103	-0.5	-0.7
Industry**	8 313	9 183	9 207	9 491	9 532	9 468	9 098	0.4	-0.0
Chemicals**	1 163	1 344	1 343	1 449	1 457	1 421	1 306	1.1	-0.1
Iron and steel**	2 111	2 730	2 800	2 774	2 737	2 686	2 509	-0.1	-0.4
Cement**	1 916	2 408	2 356	2 366	2 417	2 452	2 458	0.1	0.2
Aluminium**	175	248	250	263	266	265	266	0.7	0.2
Transport	6 965	7 944	8 213	8 537	8 198	7 840	7 557	0.6	-0.3
Road	5 181	6 028	6 137	6 221	5 799	5 378	5 027	0.2	-0.7
Passenger cars	2 658	3 083	3 168	3 011	2 668	2 376	2 137	-0.7	-1.4
Heavy-duty trucks	1 518	1 873	1 898	2 136	2 168	2 154	2 190	1.7	0.5
Aviation	746	800	941	1 158	1 266	1 363	1 491	3.0	1.7
Shipping	792	836	856	900	883	854	806	0.7	-0.2
Buildings	2 873	2 842	2 747	2 666	2 468	2 345	2 275	-0.4	-0.7
Residential	1 961	1 974	1 904	1 772	1 611	1 500	1 380	-1.0	-1.2
Services	912	867	842	894	857	846	895	0.9	0.2
Total CO_2 removals**	-	1	1	21	24	30	50	48	14
Total CO_2 captured**	16	43	40	122	192	261	395	17	8.8

*Includes industrial process and flaring emissions.
**Includes industrial process emissions.

Table A.4c: World CO_2 emissions

				Net Zero Emissions by 2050 (Mt CO_2)				CAAGR (%) 2023 to:	
	2010	2022	2023	2030	2035	2040	2050	2030	2050
Total CO_2*	32 805	37 230	37 723	25 112	13 485	6 221	-	-5.6	n.a.
Combustion activities (+)	30 566	34 290	34 789	23 082	12 143	5 678	777	-5.7	-13
Coal	13 840	15 285	15 667	8 590	3 587	1 086	158	-8.2	-16
Oil	10 479	11 219	11 334	8 149	5 334	3 208	878	-4.6	-9.0
Natural gas	6 062	7 516	7 520	6 232	3 417	1 811	391	-2.6	-10
Bioenergy and waste	186	270	267	111	-195	-428	-650	-12	n.a.
Other removals** (-)	-	1	1	182	361	586	1 069	101	28
Biofuels production	-	1	1	114	191	264	289	88	22
Direct air capture	-	-	0	68	170	322	780	n.a.	52
Electricity and heat sectors	12 513	14 943	15 262	8 861	3 054	384	-299	-7.5	-186
Coal	8 952	10 944	11 269	5 646	1 709	35	20	-9.4	-21
Oil	826	677	638	169	66	18	0	-17	-25
Natural gas	2 621	3 177	3 211	2 992	1 442	635	111	-1.0	-12
Bioenergy and waste	115	146	144	55	-163	-304	-430	-13	n.a.
Other energy sector**	1 441	1 616	1 579	770	259	74	-72	-9.7	-189
Final consumption**	18 590	20 410	20 604	15 539	10 335	6 082	1 149	-4.0	-10
Coal	4 686	4 243	4 302	2 909	1 853	1 035	127	-5.4	-12
Oil	9 020	9 909	10 108	7 601	5 005	2 994	756	-4.0	-9.2
Natural gas	2 854	3 559	3 521	2 770	1 814	1 053	196	-3.4	-10
Bioenergy and waste	71	123	124	56	-32	-124	-220	-11	n.a.
Industry**	8 313	9 183	9 207	7 204	5 059	3 067	458	-3.4	-11
Chemicals**	1 163	1 344	1 343	1 162	846	516	80	-2.0	-9.9
Iron and steel**	2 111	2 730	2 800	2 153	1 520	961	224	-3.7	-8.9
Cement**	1 916	2 408	2 356	1 796	1 260	736	65	-3.8	-12
Aluminium**	175	248	250	225	184	116	9	-1.5	-12
Transport	6 965	7 944	8 213	6 202	4 097	2 474	632	-3.9	-9.1
Road	5 181	6 028	6 137	4 585	2 904	1 655	338	-4.1	-10
Passenger cars	2 658	3 083	3 168	2 078	1 091	525	96	-5.8	-12
Heavy-duty trucks	1 518	1 873	1 898	1 725	1 357	924	220	-1.4	-7.7
Aviation	746	800	941	922	749	561	210	-0.3	-5.4
Shipping	792	836	856	524	328	184	63	-6.8	-9.2
Buildings	2 873	2 842	2 747	1 832	974	418	43	-5.6	-14
Residential	1 961	1 974	1 904	1 295	689	299	38	-5.4	-14
Services	912	867	842	538	285	118	6	-6.2	-17
Total CO_2 removals**	-	1	1	243	671	1 110	1 797	110	30
Total CO_2 captured**	16	43	40	1 023	2 540	4 001	5 924	59	20

*Includes industrial process and flaring emissions.
**Includes industrial process emissions.

NZE shipping CO2 reduction 2023-205: 856M-63M = 793M tons