Life cycle of propellants

Environmental benchmark of current "green" propellants

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Methods

The study includes

- *RP-1/LOx*
- *LH_2/LOx*
- *CH_4/LOx*
- *UDMH/NTO*
- *Ammonium perchlorate composite propellant (APCP)*

Climate change
GWP_{100} (CO2 eq.)

Ozone depletion
ODP (CFC-11 eq.)

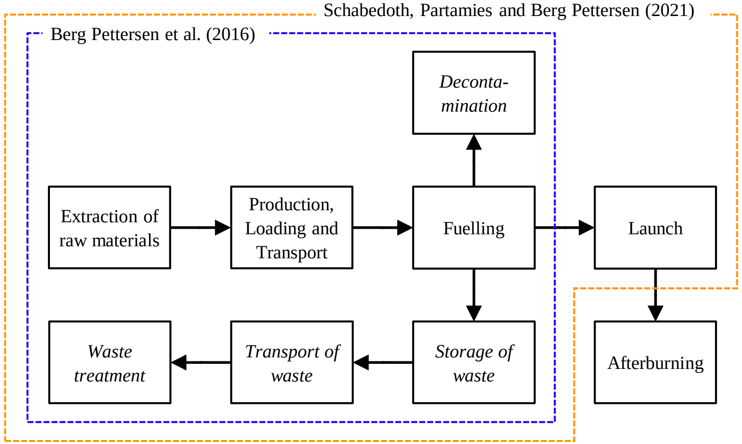
GWP_{100} beyond standard factors:
CO, H_2O, H_2, OH, NO, BC, OC, alumina (≈OC)

ODP: NO, Cl and HCl

CEARUN, i.e., no afterburning

Black carbon (BC) from literature

ESA Space LCA Database for stages up to launch



Life cycle impacts weighted by I_{SP}

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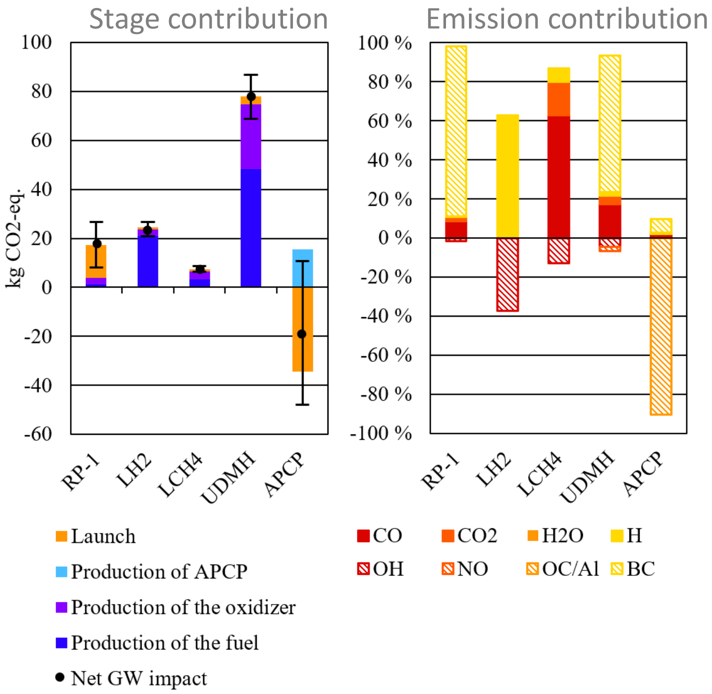
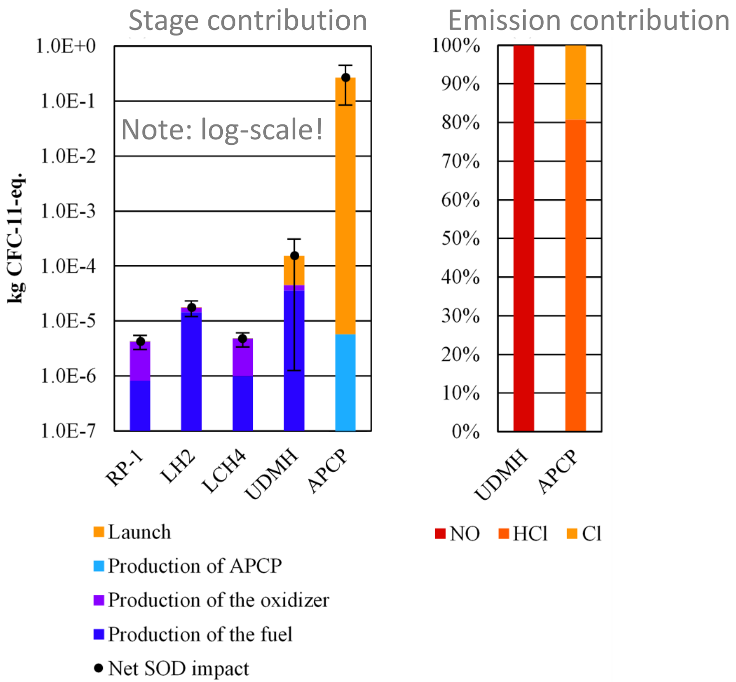


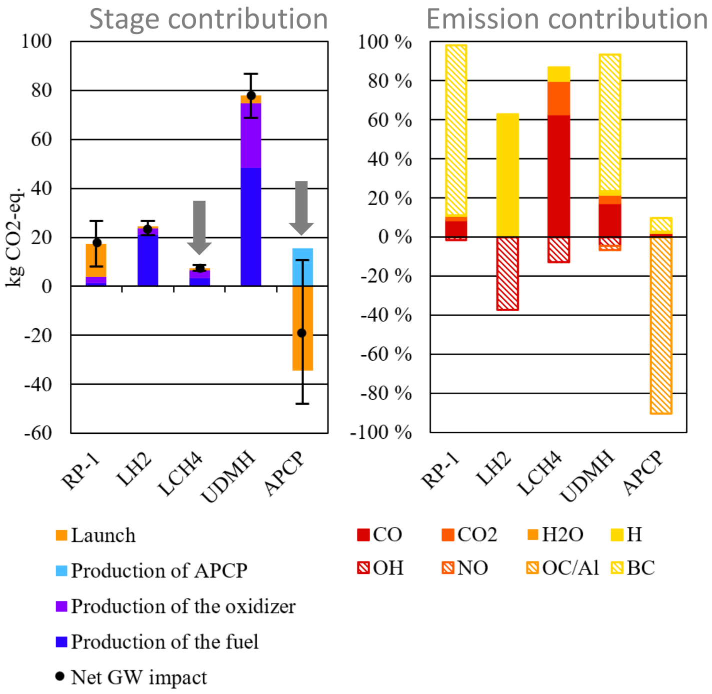
Climate change
(CO_2 eq.)

- UDMH/NTO: production
- LH_2 production
- APCP: cooling effect from alumina particulates (assumed as organic carbon, OC)
- RP-1: black carbon (BC) from launch

- Fuel (& oxidizer) production
- APCP: HCl & Cl-emissions from launch

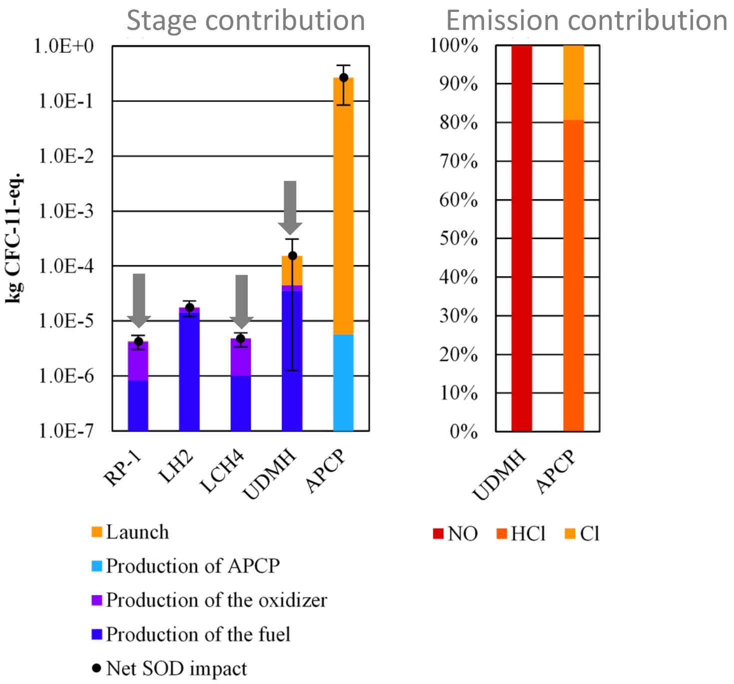


Ozone depletion
(CFC-11 eq.)



Climate change
(CO2 eq.)

LCH_4 and APCP preferred options



Ozone depletion
(CFC-11 eq.)

RP-1 and LCH_4 preferred options
Uncertainty for UDMH

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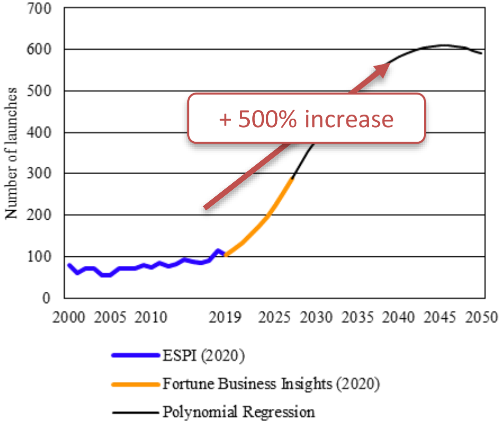
Forecast

Launch rates

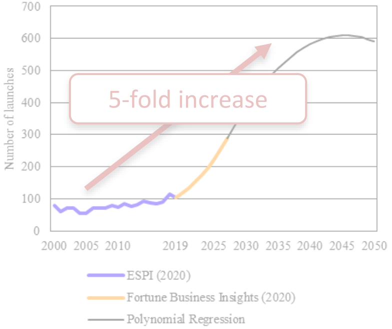


Trends

Propellant	Influence	Source	Positive / Negative	Starting from	Strength of influence
RP-1	Planned upscaling of the launch rate of the Falcon 9 and Falcon Heavy.	FAA (2020)	Positive	2020	2
	Introduction of Irtysh and Angara	ITAR-TASS News Agency (2019a, 2019b); Kyle (n.d. -b)	Positive	2020	2
	Introduction of the Long March 9	Andrew Jones (2018); Xinhua News Agency (2018)	Positive	2028	
	Cheap and easy to produce	Dallas et al. (2020)	Positive	2020	1
LH_2	Introduction of the SLS	FAA (2018; 2020)	Positive	2021	2
	Introduction of the Long March 9	Andrew Jones (2018); Xinhua News Agency (2018)	Positive	2028	2
	High I_{sp} makes it attractive to use in the future	Dallas et al. (2020)	Positive	2028	1
LCH_4	Introduction of the Starship	Henry (2019)	Positive	2021	3
	Introduction of New Glenn	Blue Origin (n.d.)	Positive	2021	2
	High I_{sp}, cheap	Pettersen et al. (2016)	Positive	2020	1
UDMH	Replacement of the Proton, Rockot until 2030	Harvey (2019)	Negative	2020	-9
	Phasing out of UDMH fuelled Chinese until 2030	Harvey (2019)	Negative	2020	-9
	Industry trend towards green propellants	Gohardani et al. (2014)	Negative	2020	-2
APCP	Introduction of the SLS and Ariane 6	ESA (n.d.); FAA (2018); Foust (2020)	Positive	2020	2
	APCP is suitable for small launchers	Dallas et al. (2020)	Negative	2020	-1

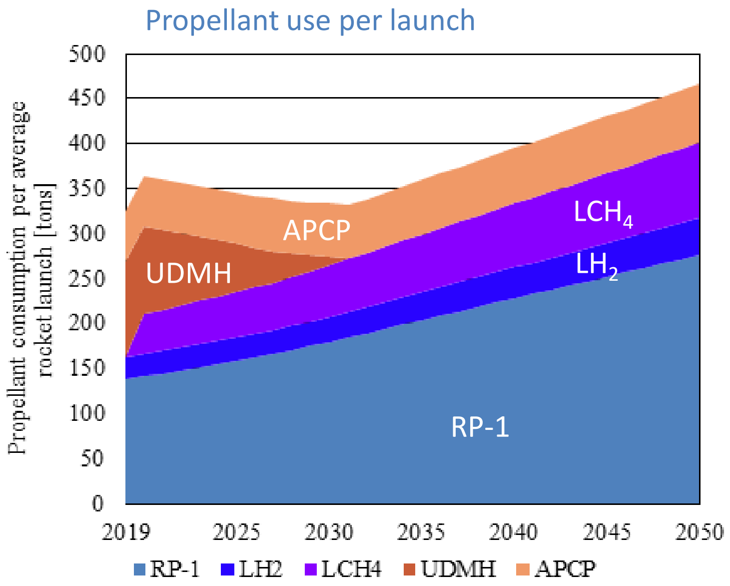
Forecast

Launch rates



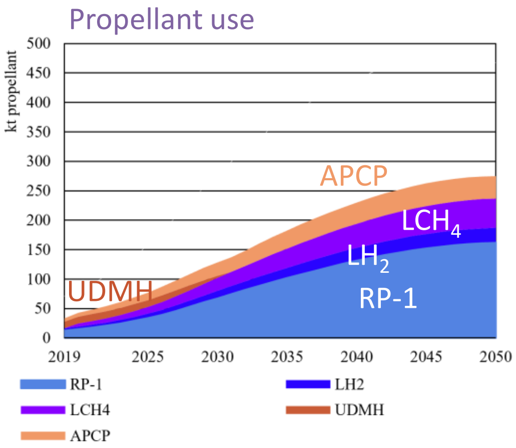
Trends

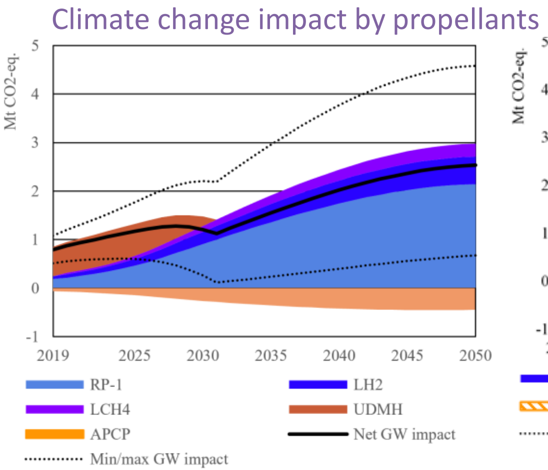
Propellant	Influence	Source	Increasing / Decreasing	Starting from
RP-1	Planned upscaling of the launch	FAA [81]	Positive	2020
			Positive	2020
			Positive	2028
			Positive	2020
			Positive	2021
			Positive	2028
			Positive	2028
			Positive	2021
			Positive	2021
			Positive	2020
			Negative	2020
			Negative	2020
			Negative	2020
			Positive	2020
			Negative	2020

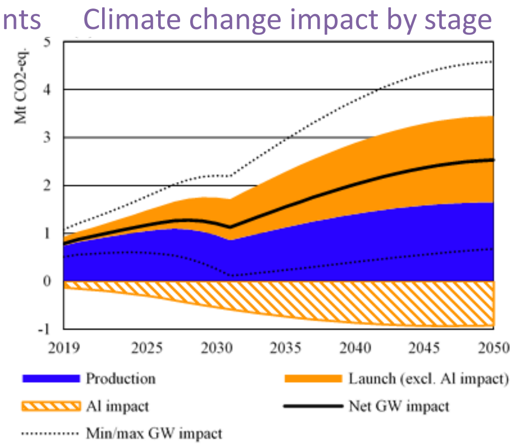


Climate change (CO2 eq.)

Slightly more than doubled towards 2050



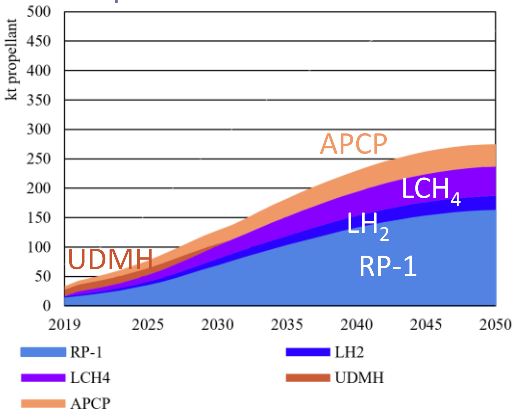




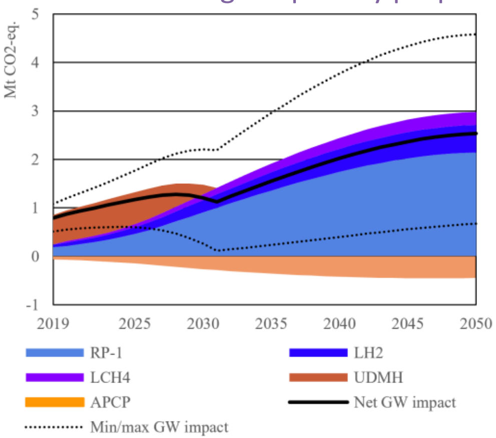
Climate change (CO2 eq.)

Slightly more than doubled towards 2050

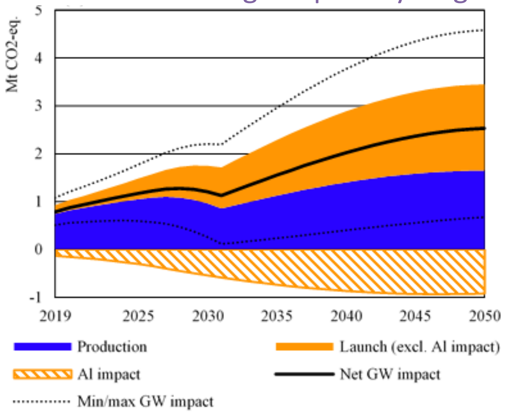
Propellant use



Climate change impact by propellants



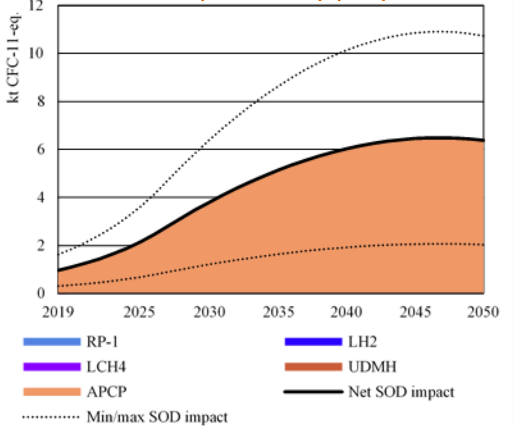
Climate change impact by stage



Ozone depletion (CFC-11 eq.)

More than 5-fold increase towards 2050

Ozone depletion by propellant



Conclusions

- Large variation in climate change and ozone depletion performance
- Some propellants stand out as better candidates
- Life cycle perspective is necessary to evaluate the alternatives
- Stabilization of global impacts from rocket launches requires transitioning towards propellants with lower life cycle impacts

Limitations

This represents a **first** attempt at consistent life cycle assessment of propellants

- Launch stage emissions are estimated from simulation: could be improved or validated
- We have estimated ODP factors for launch rate emissions, especially chlorines
- We have adopted GWP_{100} factors for the range of emissions
- We have assumed that alumina particulates have a cooling effect (uncertain)
- Emissions were assumed to be emitted at ground level due to methodological constraints

Abstract

Life cycle of propellants: environmental benchmark of current "green" propellants

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European Space Agency (ESA) has previously established life cycle data for life stages up to launch. In this work we extend the previous ESA LCA data and present complete life cycle assessment of several current propellants, including propellant chemical production, loading and launch stage emissions with impacts to climate change and ozone depletion. CEARUN was used to estimate launch stage emissions.

The life cycle performance of RP-1/LOx, LH2/LOx, CH4/LOx, UDMH/NTO and solid ammonium perchlorate composite propellant (APCP) is benchmarked per specific impulse.

Results clearly show the importance of including emissions both before and during launch, e.g., production stage emissions dominate for climate change emissions from hydrogen and UDMH, and launch emissions from APCP overrule any other contribution to ozone depletion. Some of the propellants carry climate cooling effects through emissions of reflective particulates, while others contribute to increased radiative forcing by emission of black carbon.

*We make emission forecasts from global launch rates towards 2050, to project climate change emissions (GWP100) and ozone depletion, and findings from these underline the importance of the ongoing shift towards certain propellants. We conclude that, under some conditions, hydrogen and methane appear good candidates for the future. Results have been submitted to a relevant journal (**in prep.**)*