Evaluating GHGs from Transportation: Alternative Fuels and Alternative Metrics

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Booz Allen Hamilton

October 6, 2014

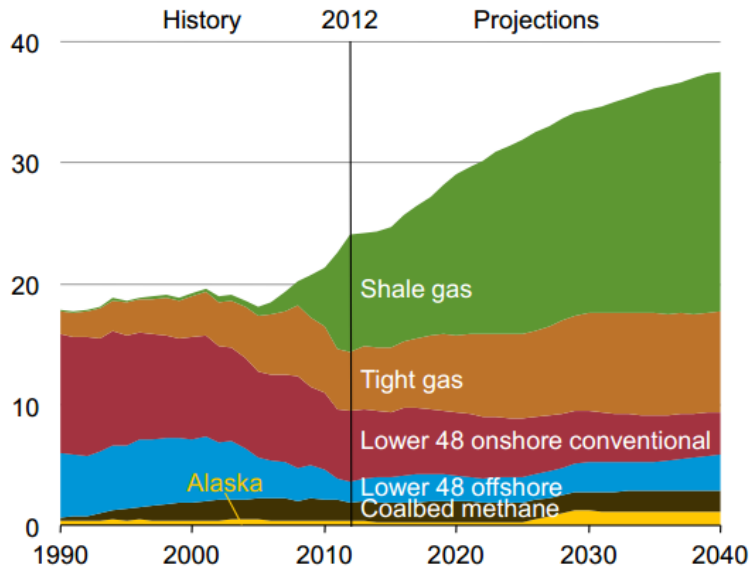
U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

OFFICE OF FOSSIL ENERGY

Research background

- **Large increase in domestic natural gas**
  - Potential for use in transportation
  - Can power light duty vehicles:
    - Directly (CNG)
    - As feedstock to make liquid fuels
    - As electricity

Figure MT-44. U.S. natural gas production by source in the Reference case, 1990-2040 (trillion cubic feet)



- **Disagreement in literature about how to compare impacts of CO_2 and methane**
  - 20 verses 100 year GWP
  - GTP rather than GWP?
  - Directly calculate forcing/temperature

http://www.eia.gov/petroleum/drilling/pdf/marcellus.pdf

Research background

- **Disagreement over leakage rate**
  - Highly variable depending on temporal and geographic representation – work is needed to reconcile differences
  - We use expected leakage of 1.2% (NETL, 2014), high of 4% (Schwietzke *et al*, 2014)

Life Cycle Analysis of Natural Gas Extraction and Power Generation

May 29, 2014

DOE/NETL-2014/1646

GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 4393–4397, doi:10.1002/grl.5

Methane emissions estimate from airborne measurements over a western United States natural gas field

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Alan Brewer,
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Received 12 June

[1] Methane
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Measurements of methane emissions at natural gas production sites in the United States

David T. Allen[a,1], Vincent M. Torres[a], James Thomas[a], David W. Sullivan[a], Matthew Harrison[b], Al Hendler[b], Scott C. Herndon[c], Charles E. Kolb[c], Matthew P. Fraser[d], A. Daniel Hill[e], Brian K. Lamb[f], Jennifer Miskimins[g], Robert F. Sawyer[h], and John H. Seinfeld[i]

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Edited by Susan L. Brantley, Pennsylvania State University, University Park, PA, and approved August 19, 2013 (received for review March 20, 2013)

Engineering estimates of methane emissions from natural gas production have led to varied projections of national emissions. This work reports direct measurements of methane emissions at 190 onshore natural gas sites in the United States (150 production sites, 27 well completion flowbacks, 9 well unloadings, and 4 workovers). For well completion flowbacks, which clear fractured wells of liquid to allow gas production, methane emissions ranged from 0.01 Mg to 17 Mg (mean = 1.7 Mg; 95% confidence bounds of 0.67–3.3 Mg), compared with an average of 81 Mg per event in the 2011 EPA national emission inventory from April 2013. Emission factors for pneumatic pumps and controllers as well as equipment leaks were both comparable to and higher than estimates in the national inventory. Overall, if emission factors from this work for

and liquids in the formation to migrate to the production well. The well and formation is partially cleared of liquids in a process referred to as a completion flowback, after which the well is placed into production. Production of natural gas from shale formations (shale gas) accounts for 30% of US natural gas production, and this percentage is projected to grow to more than 50% by 2040 (4).

Multiple analyses of the environmental implications of gas production using hydraulic fracturing have been performed, including assessments of water contamination (5–8), criteria air pollutant and air toxics releases (9–11), and greenhouse gas emissions (11–18). Greenhouse gas emission analyses have generally been based on either engineering estimates of emis-

ENVIRONMENTAL Science & Technology

Policy Analysis

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Natural Gas Fugitive Emissions Rates Constrained by Global Atmospheric Methane and Ethane

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ne emissions released by the
cal and uncertain value for
such as for determining the
r coal. Previous studies have
(FER)—the fraction of
d ethane) escaped to the
ost of these studies rely on
d some may represent only
shots. This study estimates
using global atmospheric
s over three decades, and
ospheric lifetimes, (ii) non-
ed fugitive gas hydrocarbon
its an upper bound global
11, and a most likely FER of 2−4% since 2000, trending downward. These results do not
ydrocarbon seepage, which could lower the FER. Further emissions reductions by the NG
limate benefits over coal during the next few decades.

:hange using natural gas
gy-dominated economy
ggesting that methane
ould outweigh reduced
Other studies[5–6] indicate

cycle CH_4 emissions is sometimes reported as the NG fugitive emissions rate (FER), defined here as the percentage of dry production—mainly CH_4—that is lost throughout its life cycle.

Most literature FER estimates were generated using bottom-up approaches, that is, aggregating measurements and engineering estimates at different life cycle stages. Previous

Alternative fuels examined and metrics used

- **Comparison of conventional gasoline & diesel in cars with alternate fuels derived from natural gas**
  - Electricity (plug-in hybrid [PHEV], battery-electric [BEV])
  - Compressed natural gas (CNG)
  - Gas to liquids (GTL) diesel
  - Ethanol (E85) & methanol (M85)

Fuel	MPGGE	Grams per km
Gasoline	33	53.1
Diesel	34	50.3
HEV	45	38.9
CNG	31	46.4
E85	33	76.6
M85	35.3	89.8

- **Use over three timeframes**
  - Instant (1 passenger-km) – battery mfg. included
  - Vehicle lifetime (15 years) – battery mfg. at start
  - Fuel infrastructure lifetime (80 years) – battery mfg. spread out

Metric	Definition	Emission Type	Metric Type
Global warming potential (GWP)	CRF from a pulse emission at t=0	Pulse	Integrated
Global temperature potential (GTP)	Direct increase in temperature from a pulse at t=0; calculated from RF	Pulse	Instant
Radiative forcing (RF)	Direct increase in forcing from GHGs (W/m^2)	Continuous	Instant
Cumulative radiative forcing (CRF)	Total of all forcing; integration of RF over time horizon	Continuous	Integrated

Vehicle and emissions data from: Tong, F., Jaramillo, P., Azevedo, I.A. Comparison of Life Cycle Greenhouse Gases from Natural Gas Pathways for Road Transportation – Part I: Light Duty Vehicles. 2014.

Data sources

- **NETL**
  - Petroleum fuels
  - Natural gas extraction through transport
  - Natural gas electricity production
  - GTL diesel with CCS

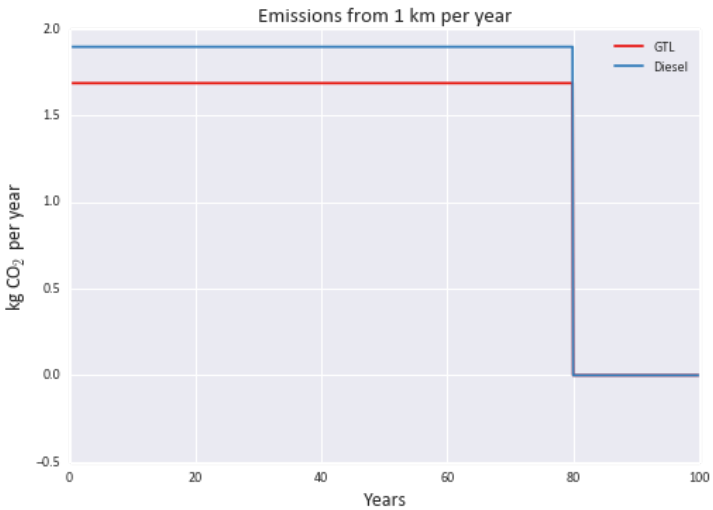
- **Carnegie Mellon University**
  - Vehicle fuel use
  - Ethanol
  - Methanol
  - CNG

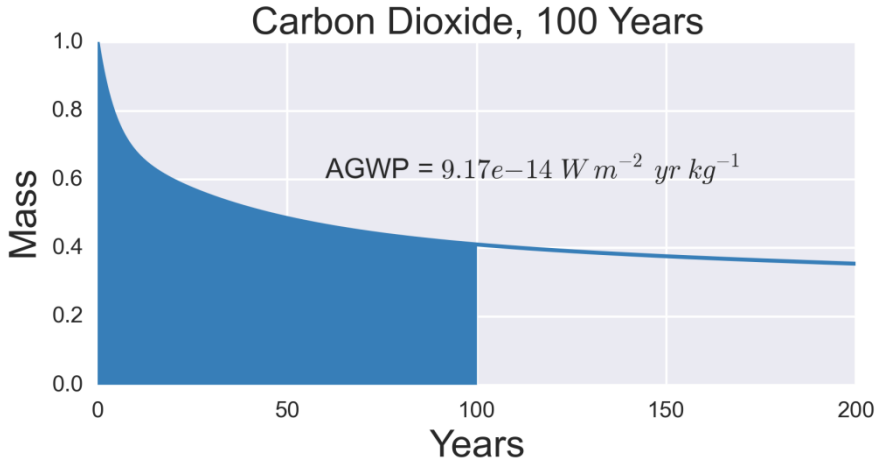
Vehicle and emissions data from: Tong, F., Jaramillo, P., Azevedo, I.A. Comparison of Life Cycle Greenhouse Gases from Natural Gas Pathways for Road Transportation – Part I: Light Duty Vehicles. 2014.

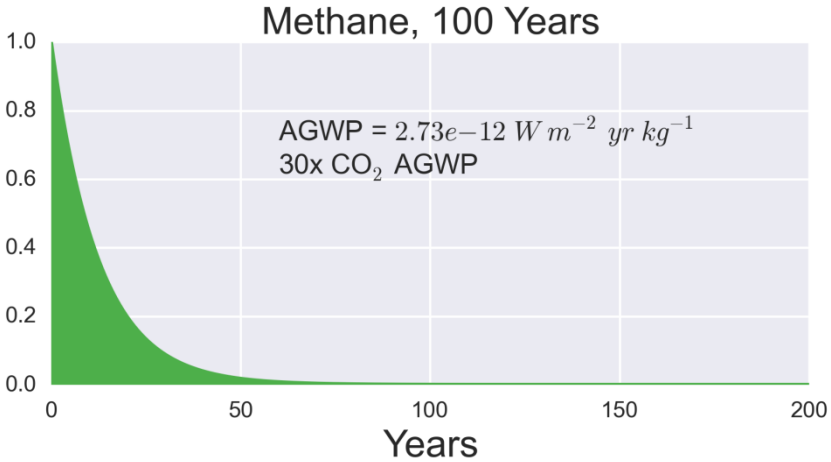
Alt metrics can be calculated from equations in AR5

- **GTP and GWP represent instant & integrated metrics from pulse emissions**

- **It is possible to calculate forcing (instant) & cumulative forcing (integrated) from continuous emissions**







The "function" part of functional unit is important

- **System lifetime matters when metrics account for emissions over time**
  - 1 passenger-km, use GWP/GTP
  - 15 years is the vehicle lifetime, time effects start to appear
  - 80 years is on the scale of a fuel system infrastructure lifetime

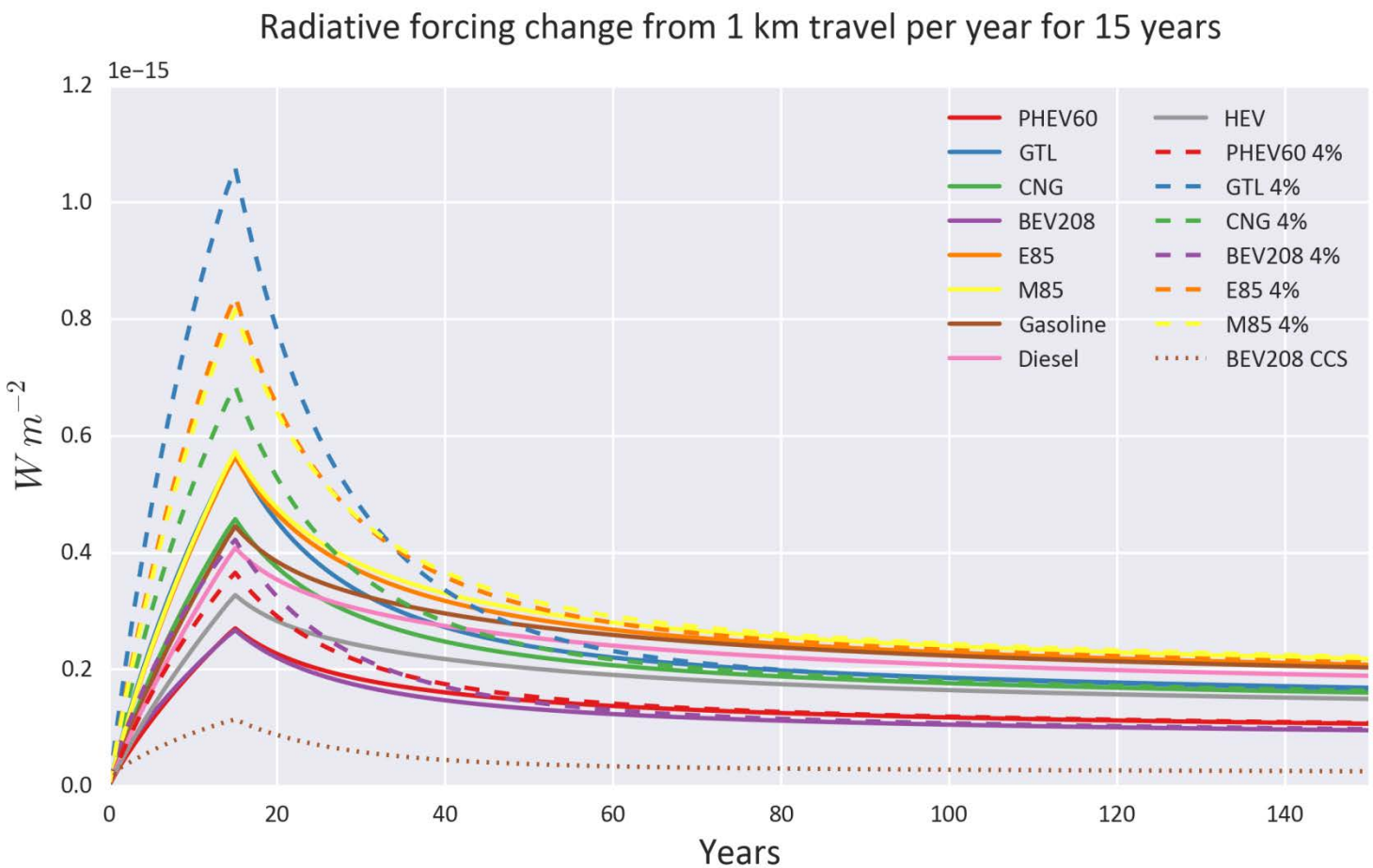
- **Functional unit: 1 passenger-km per year for the life of each system**
  - Comparison of equal travel
  - No attempt to predict how vehicle use will change over time

Goal is to compare fuels against each other over a range of time frames and metrics – no need to normalize to a single distance

Results shown in physical units

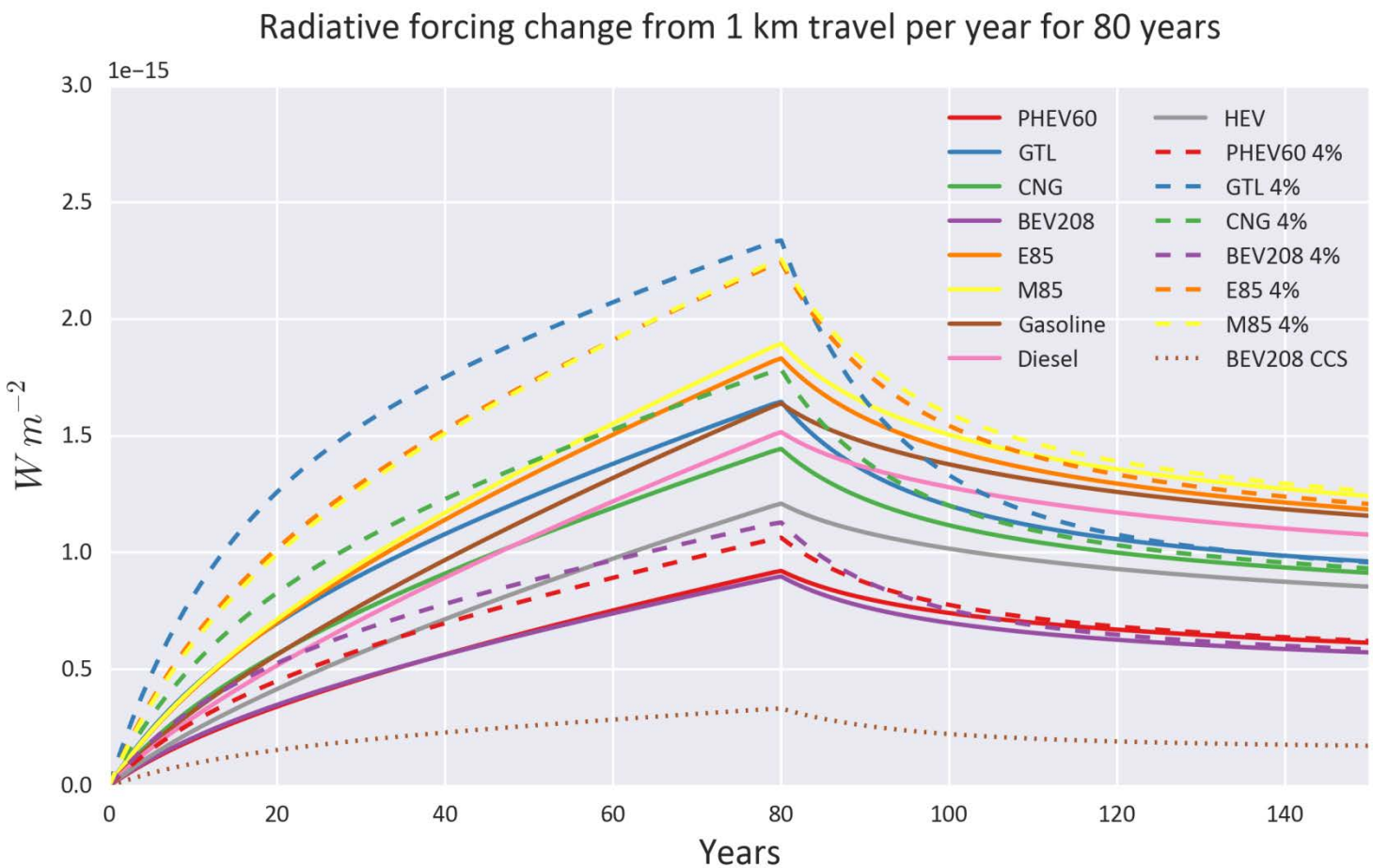
- **Visual display in physical units over time**
- **Shows relative magnitude of different systems**
  - Compared to each other
  - As they progress over time
- **Lots of information**

Vehicle lifetime radiative forcing



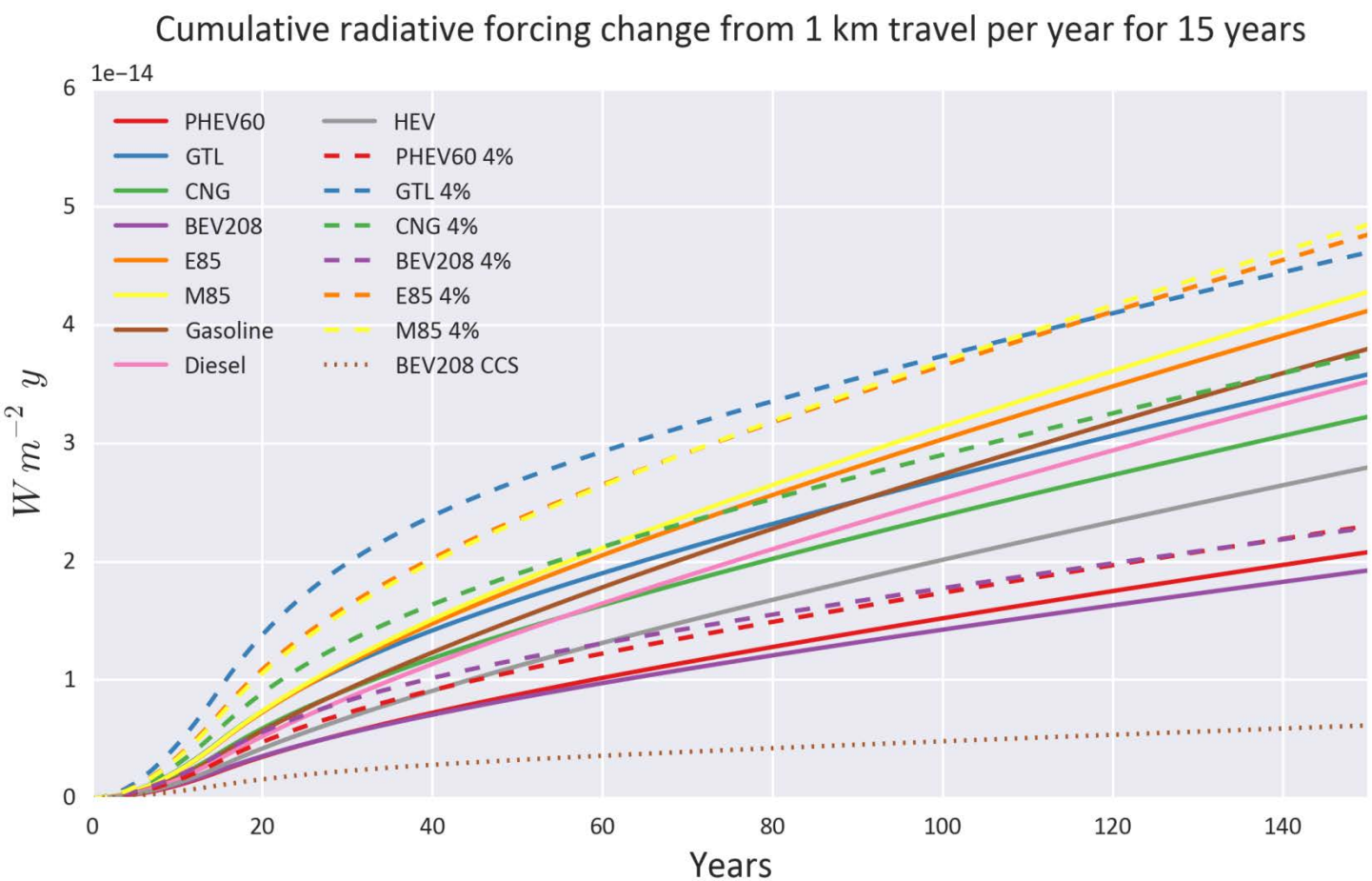
- **Sharp peak, then quick drop from high methane scenarios**
- **Separation of PHEV & BEV fuels from the rest over time**

Infrastructure lifetime radiative forcing



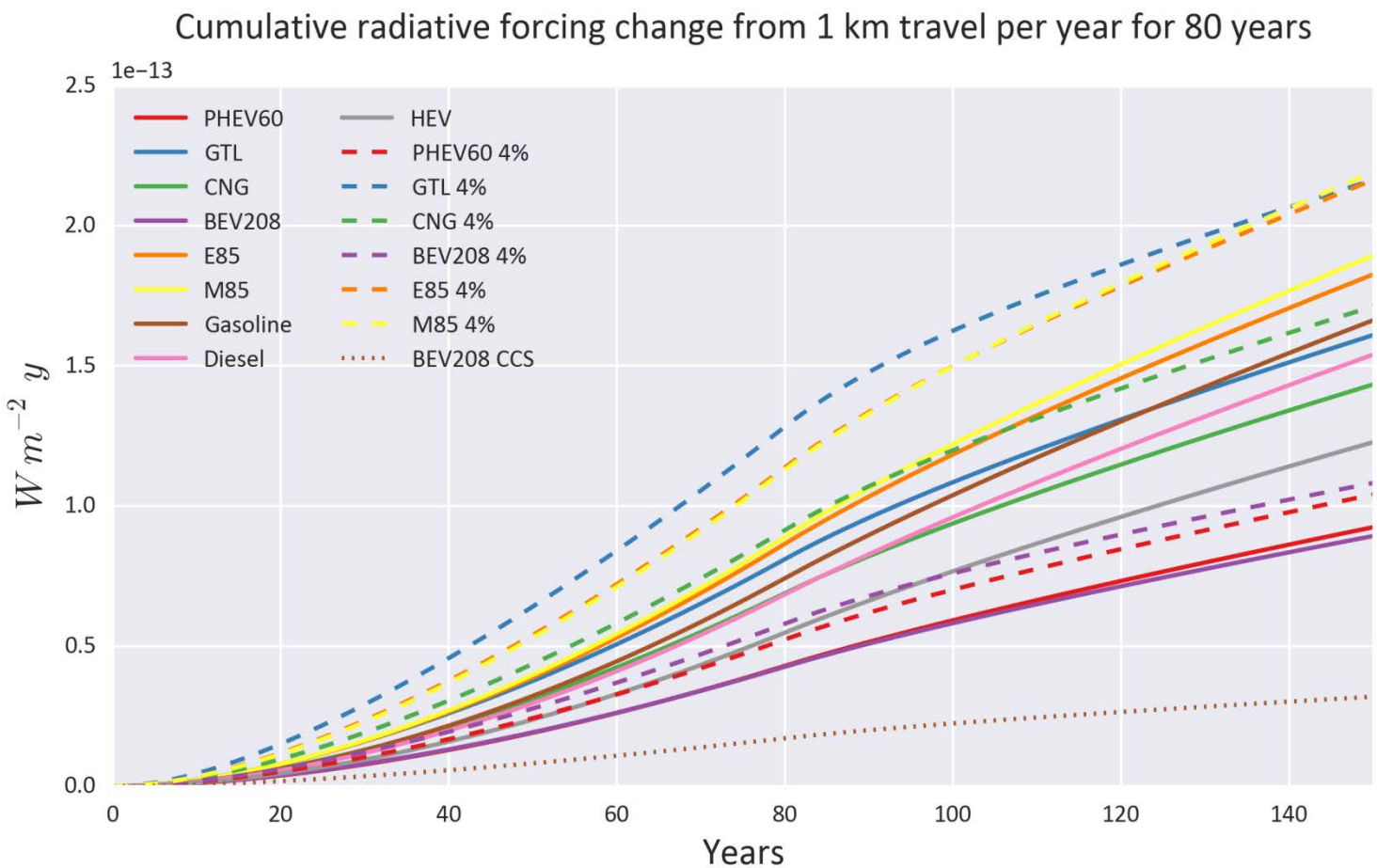
- **Methane becomes less important later in system life**
- **Differences in early impact are small compared to later in life**

Vehicle lifetime cumulative forcing



- **Longer for high leakage scenarios to drop**
- **Still see separation of PHEV & BEV fuels from the rest over time**

Vehicle lifetime cumulative forcing



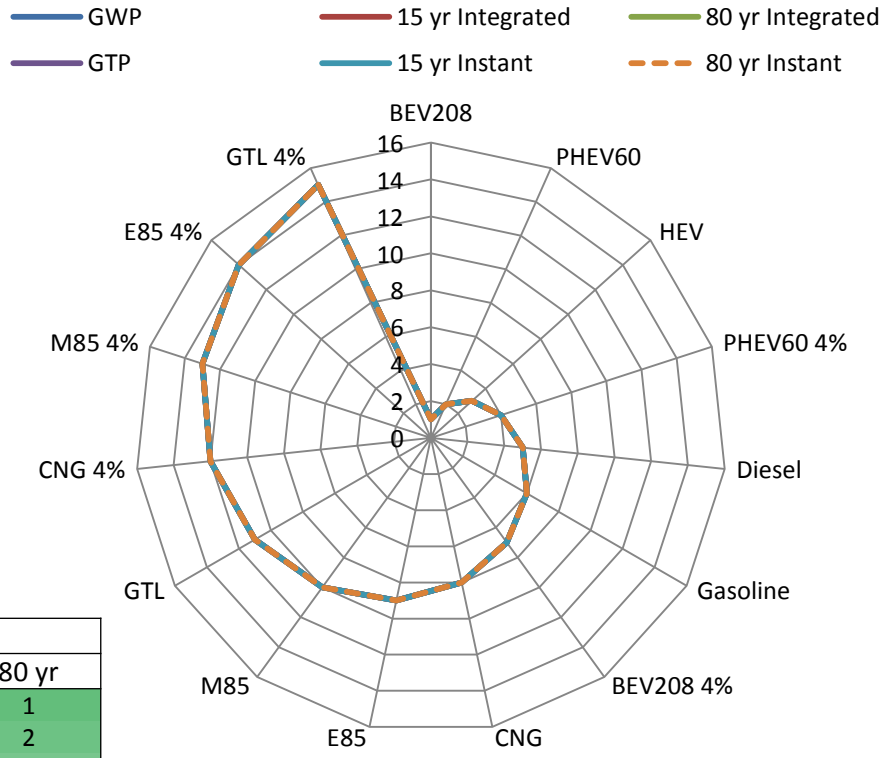
- **Longer for high leakage scenarios to drop**
- **Still see separation of PHEV & BEV fuels from the rest over time**

Results shown in rank order over time

- **Focus on several individual time frames**
- **Does not give relative magnitude or size of difference**
- **Allows for display of many metrics and functional units at once**

Initial Order (1 year)

- **Electric and standard hybrids begin with lowest impact**
- **Conventional diesel and gasoline better than most alt fuels**
- **High leakage alt fuels start with highest impact**

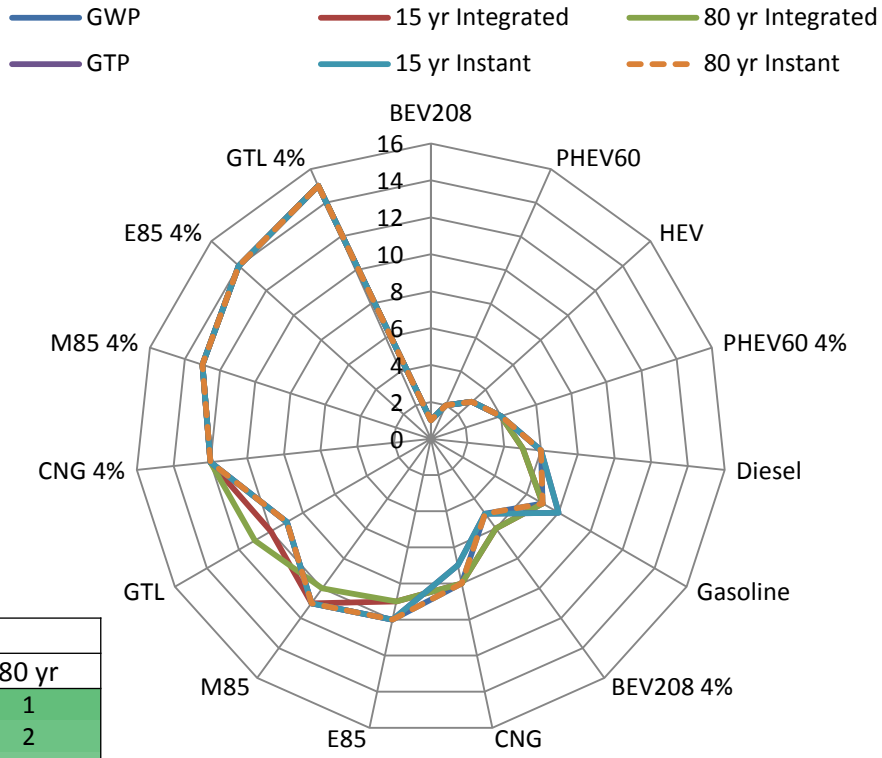


Closer to center is better

	Integrated			Instant		
1 year order	GWP	15 yr	80 yr	GTP	15 yr	80 yr
BEV208	1	1	1	1	1	1
PHEV60	2	2	2	2	2	2
HEV	3	3	3	3	3	3
PHEV60 4%	4	4	4	4	4	4
Diesel	5	5	5	5	5	5
Gasoline	6	6	6	6	6	6
BEV208 4%	7	7	7	7	7	7
CNG	8	8	8	8	8	8
E85	9	9	9	9	9	9
M85	10	10	10	10	10	10
GTL	11	11	11	11	11	11
CNG 4%	12	12	12	12	12	12
M85 4%	13	13	13	13	13	13
E85 4%	14	14	14	14	14	14
GTL 4%	15	15	15	15	15	15

20 years

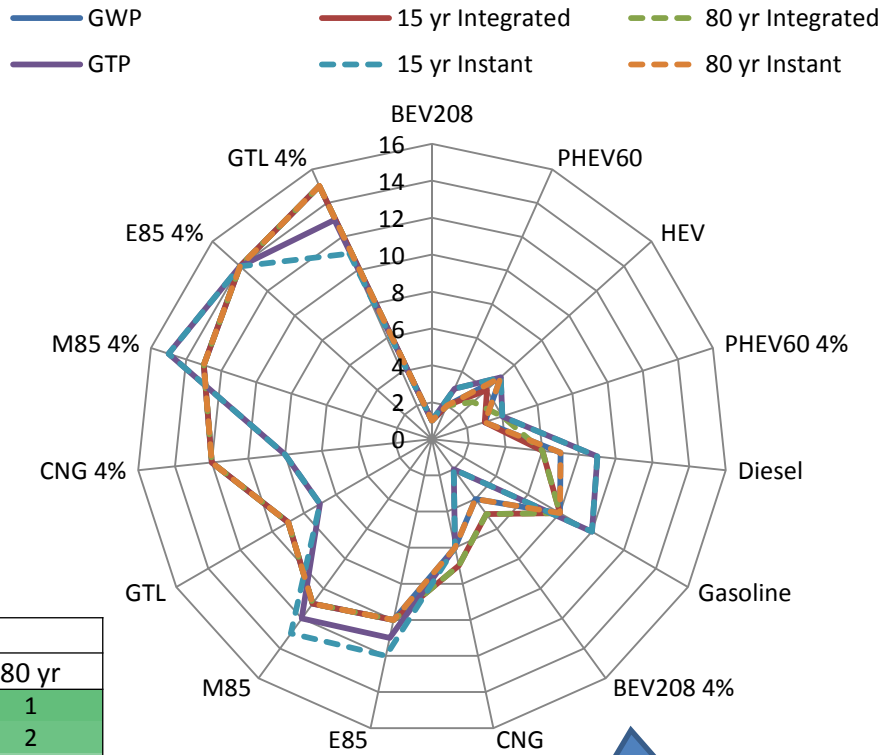
- **More movement in instant metrics**
- **Least change in 80 year integrated rankings**
- **Improvement in high leakage BEV and GTL**



	Integrated			Instant		
20 year order	GWP	15 yr	80 yr	GTP	15 yr	80 yr
BEV208	1	1	1	1	1	1
PHEV60	2	2	2	2	2	2
HEV	3	3	3	3	3	3
PHEV60 4%	4	4	4	4	4	4
Diesel	6	5	5	6	6	6
Gasoline	7	7	7	8	8	7
BEV208 4%	5	6	6	5	5	5
CNG	8	8	8	7	7	8
E85	10	9	9	10	10	10
M85	11	11	10	11	11	11
GTL	9	10	11	9	9	9
CNG 4%	12	12	12	12	12	12
M85 4%	13	13	13	13	13	13
E85 4%	14	14	14	14	14	14
GTL 4%	15	15	15	15	15	15

50 years

- **Movement in the integrated metrics**
- **Significant improvement in high leakage BEV**
- **Diesel and gasoline getting worse**

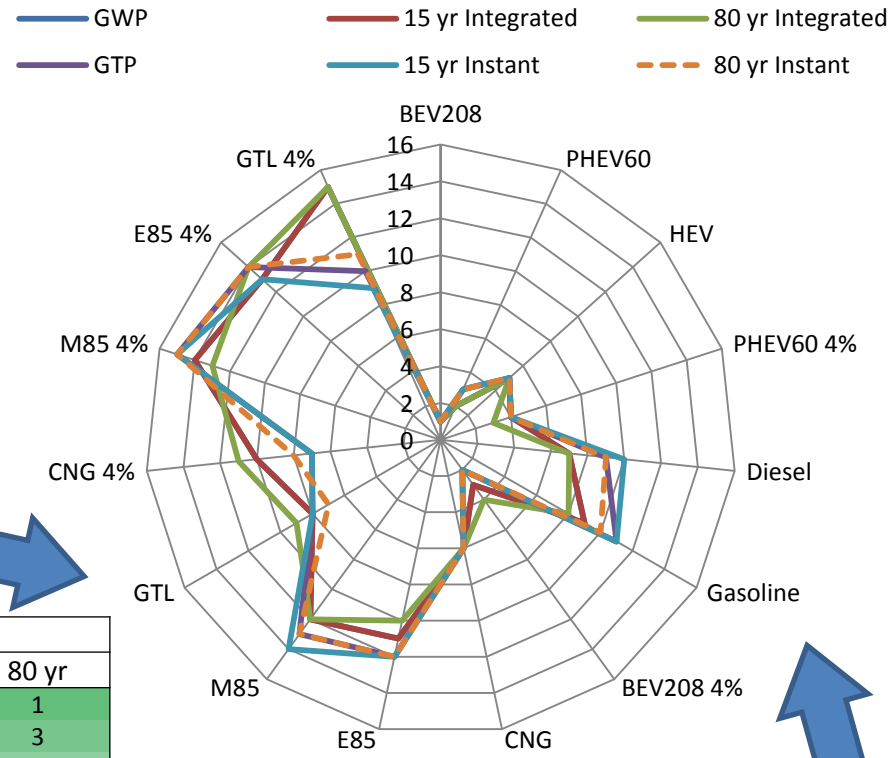


	Integrated			Instant		
50 year order	GWP	15 yr	80 yr	GTP	15 yr	80 yr
BEV208	1	1	1	1	1	1
PHEV60	2	2	2	3	3	2
HEV	5	4	3	5	5	5
PHEV60 4%	3	3	4	4	4	3
Diesel	7	6	6	9	9	7
Gasoline	8	8	8	10	10	8
BEV208 4%	4	5	5	2	2	4
CNG	6	7	7	6	6	6
E85	10	10	10	11	12	10
M85	11	11	11	12	13	11
GTL	9	9	9	7	7	9
CNG 4%	12	12	12	8	8	12
M85 4%	13	13	13	15	15	13
E85 4%	14	14	14	14	14	14
GTL 4%	15	15	15	13	11	15

High leakage electricity improving

100 years

- **Liquid fuels are moving outward for all metrics**
- **Able to see the different metrics move out in waves**



GTL improving over time

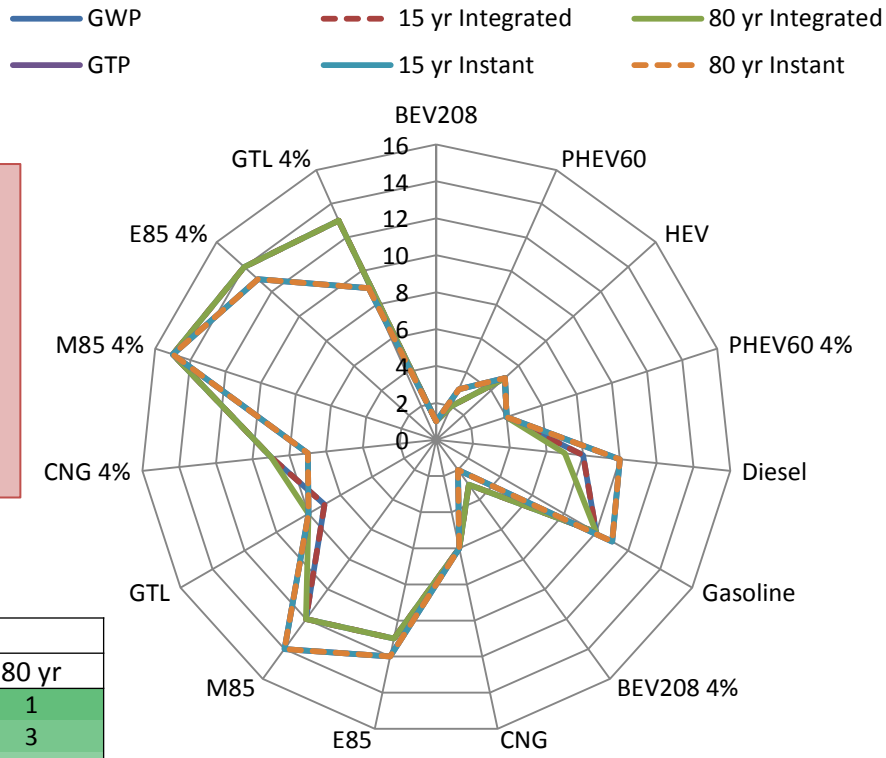
100 year	Integrated			Instant		
	GWP	15 yr	80 yr	GTP	15 yr	80 yr
BEV208	1	1	1	1	1	1
PHEV60	2	2	2	3	3	3
HEV	5	5	5	5	5	5
PHEV60 4%	4	4	3	4	4	4
Diesel	7	7	7	9	10	9
Gasoline	9	9	8	11	11	10
BEV208 4%	3	3	4	2	2	2
CNG	6	6	6	6	6	6
E85	11	11	10	12	12	12
M85	12	12	12	13	14	13
GTL	8	8	9	8	8	7
CNG 4%	10	10	11	7	7	8
M85 4%	14	14	13	15	15	15
E85 4%	13	13	14	14	13	14
GTL 4%	15	15	15	10	9	11

Petroleum fuels moving outward

Long run order

Rank order results help show trends & how systems change over time

- **Electricity is better than liquid fuels**
- **High leakage systems improve over time due to short methane lifetime**



Long run	Integrated			Instant		
	GWP	15 yr	80 yr	GTP	15 yr	80 yr
BEV208	1	1	1	1	1	1
PHEV60	2	2	2	3	3	3
HEV	5	5	5	5	5	5
PHEV60 4%	4	4	4	4	4	4
Diesel	8	8	7	10	10	10
Gasoline	10	10	10	11	11	11
BEV208 4%	3	3	3	2	2	2
CNG	6	6	6	6	6	6
E85	11	11	11	12	12	12
M85	12	12	12	14	14	14
GTL	7	7	8	8	8	8
CNG 4%	9	9	9	7	7	7
M85 4%	15	15	15	15	15	15
E85 4%	14	14	14	13	13	13
GTL 4%	13	13	13	9	9	9

Conclusions

- **Electricity is consistently the best way to power LDV**
- **Different metrics and system lifetimes can lead to different results**
- **All metrics give results that change over time**
- **The time length of a functional unit matters**

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