Assessment of Indian Hydrogen Ecosystem

Well to Wheel Approach

Sachin Chugh, DGM (Alternative Energy), IndianOil R&D

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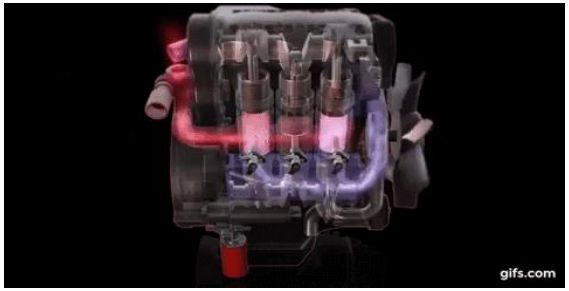
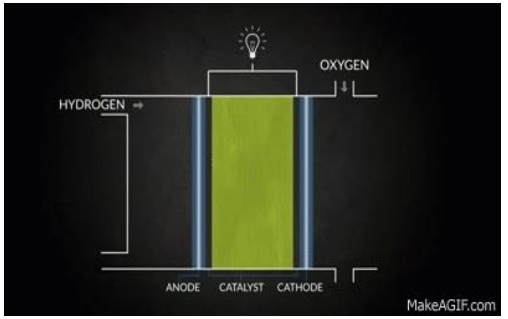
Rolling the Pitch



Correcting the Past

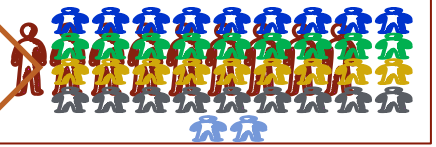
Air is not free
Water is a precious source



Ambient O2 ⇒ CO2

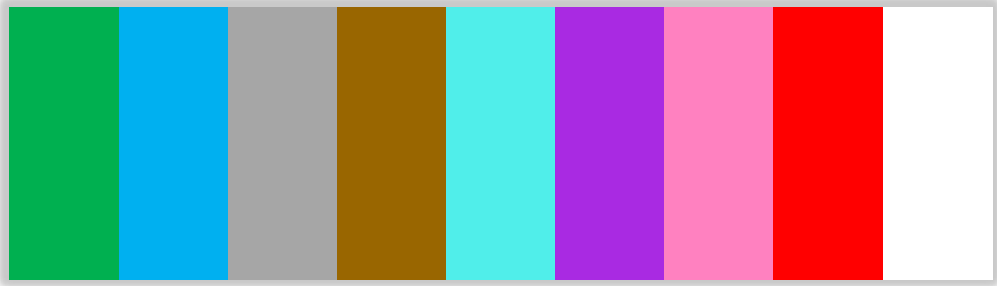
@50 kmph for 1 hr: 97,500 liters of air
Human being needs 11000 liters per day of air for breathing

1 bus for 1 hr – takes away air needed by 38 people for whole day



@50 kmph for 1 hr:
1 car for 1 hr – consumes 31000 liters of air (68% less)
Converts it into 4.5 lts of drinking water

Assessment Matters:
Primary & Secondary production pathways
Utilization of the fuel

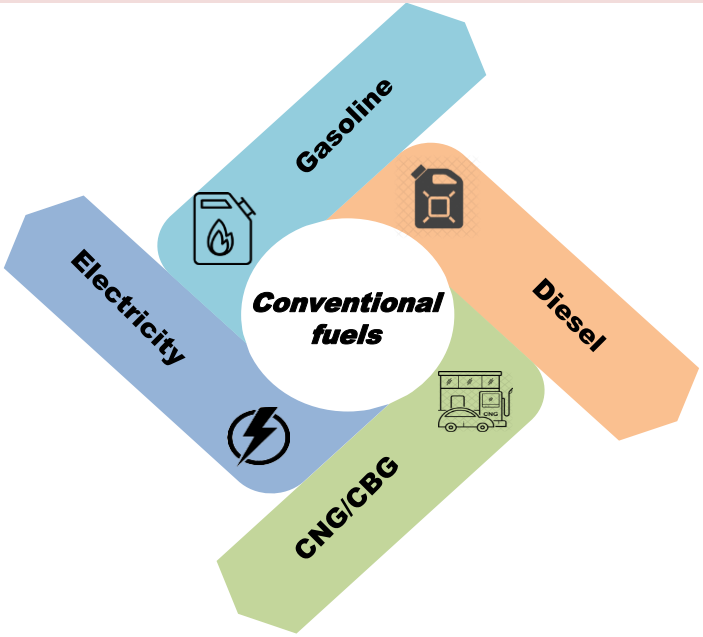


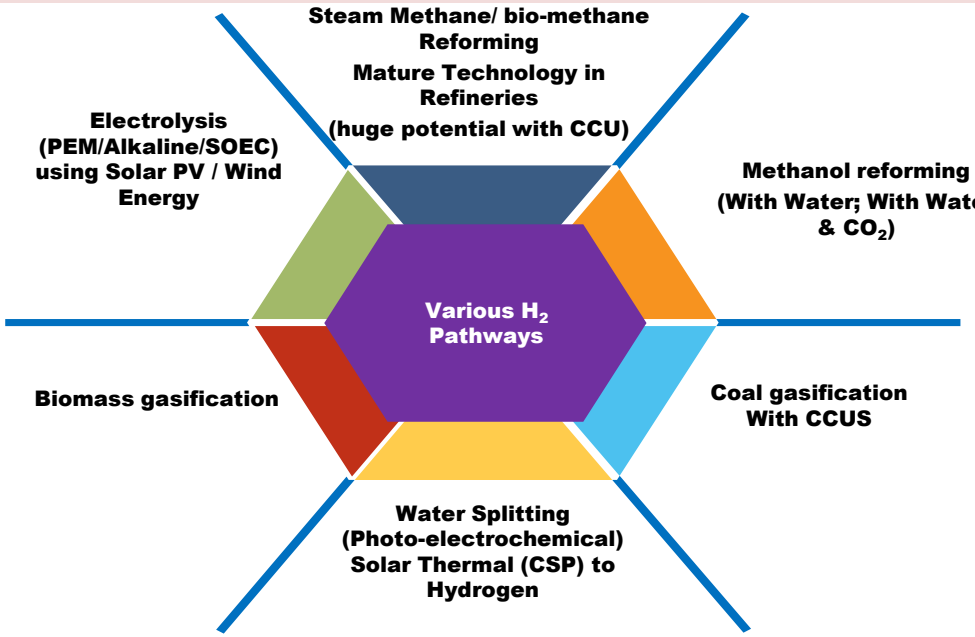
Hydrogen Rainbow

- **CO2eqv**
- **Energy**
- **Water**

Production pathways

India specific Well to Wheel Energy & Emissions needed for quantification of benefits – GREET Model Used





India specific GREET Model

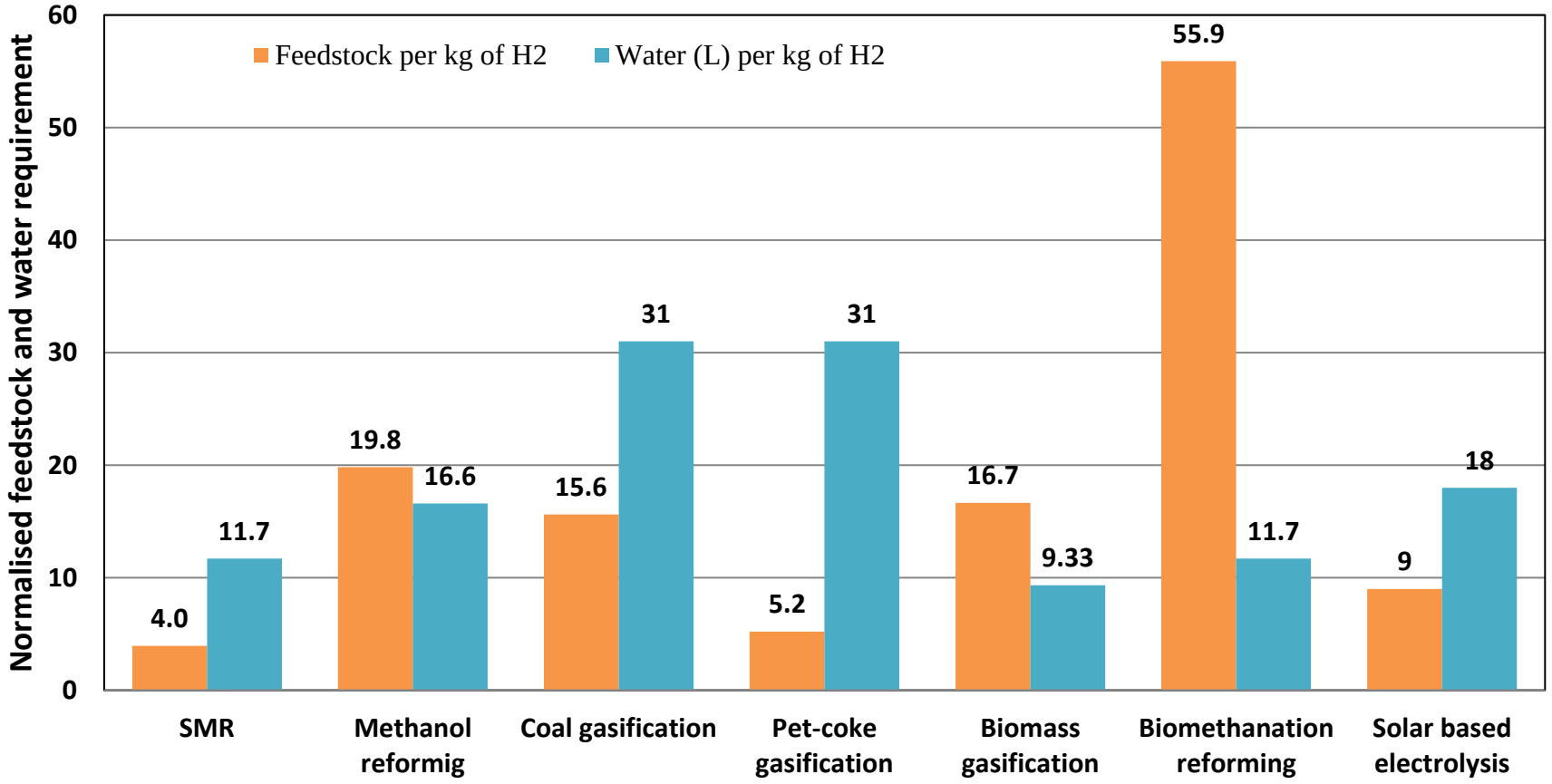
Energy production from various primary sources

Sl. No.	Source of Energy	Distinguished Features for Indian conditions
1	Crude Oil	% import, size of refinery, complexity of refinery, fuel slate, hydrogen consumption for quality upgradation of liquid fuels, transportation inefficiencies etc.
2	Natural Gas	% import, losses in re-gasification/extraction, pipeline transport losses
3	Electricity	% share of fossil fuels is the grid capacity, power generation efficiency, transmission & distribution losses, Plant load factor/ capacity utilization factor of solar energy etc.
4	Methanol	Quality of coal/ ash content, calorific value, fuel economy of transportation system etc.
5	Biomass	Type of biomass availability, segregation efficiency, conversion technology etc.
6	Solar	DNI of solar energy/ Conversion & transmission losses etc

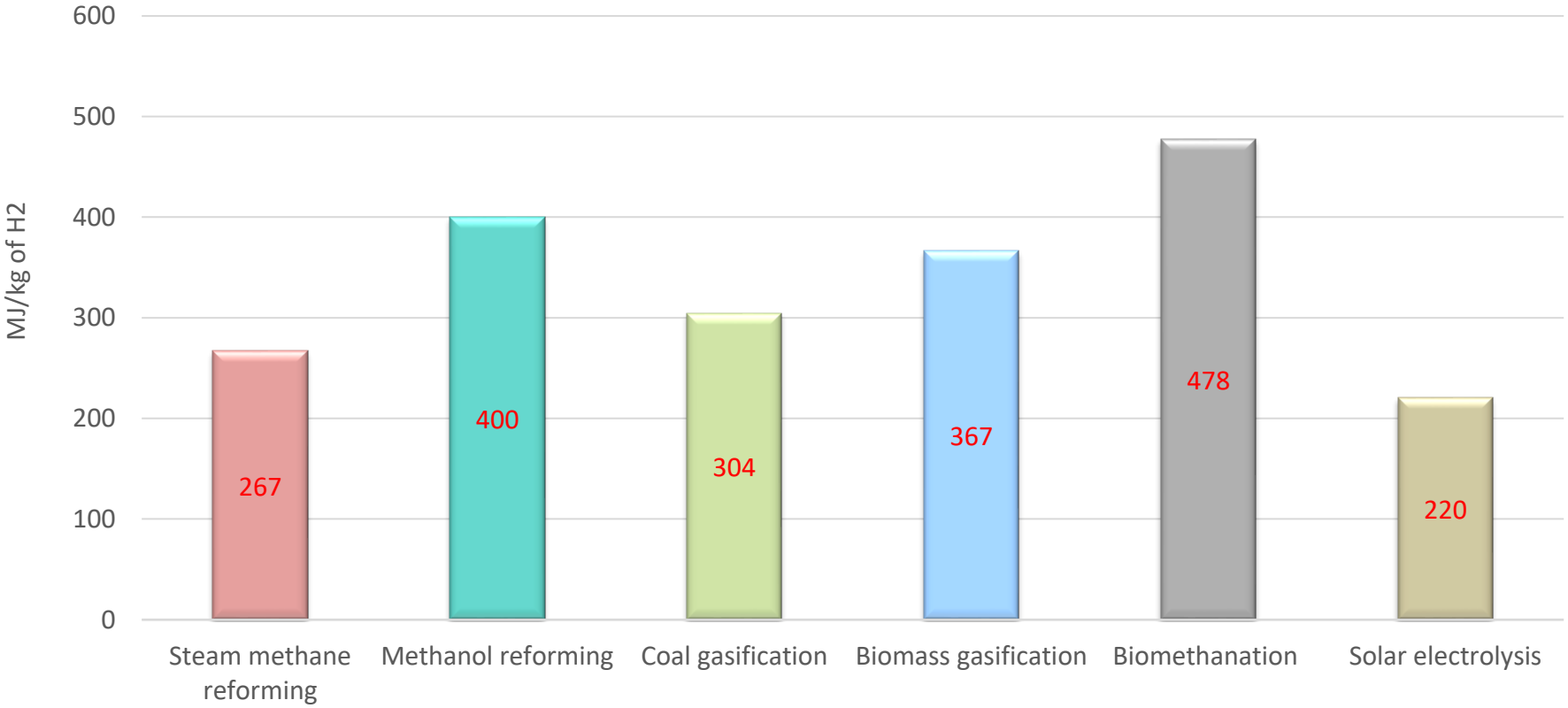
Distinguished process parameters considered for India specific study

Energy Production (Primary Energy Sources)	Energy Transportation (Primary & Secondary)	Energy Conversion / Utilization
Coal	Road (Trucks)	IC Engines
Crude Oil	Rail	Batteries (Motors)
Natural Gas	Pipelines	Fuel Cells (Motors)
Biomass	Grid Transmission	
Solar	Ocean tankers	

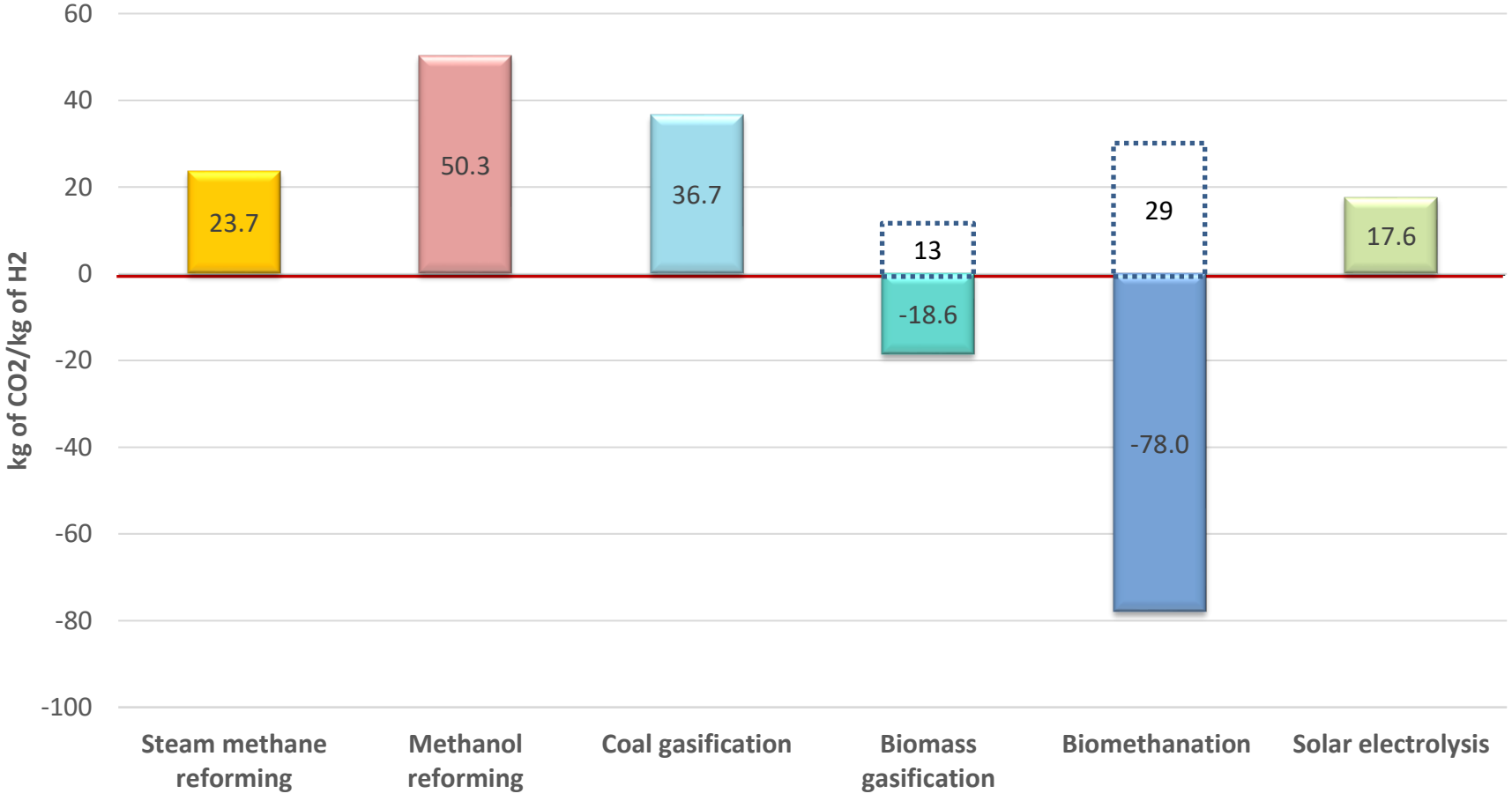
Raw material Assessment



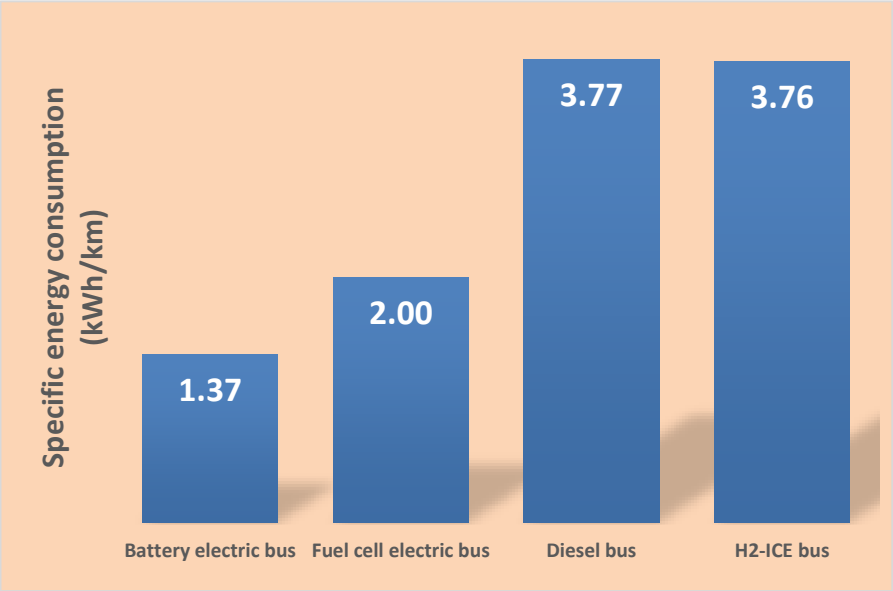
Energy Analysis



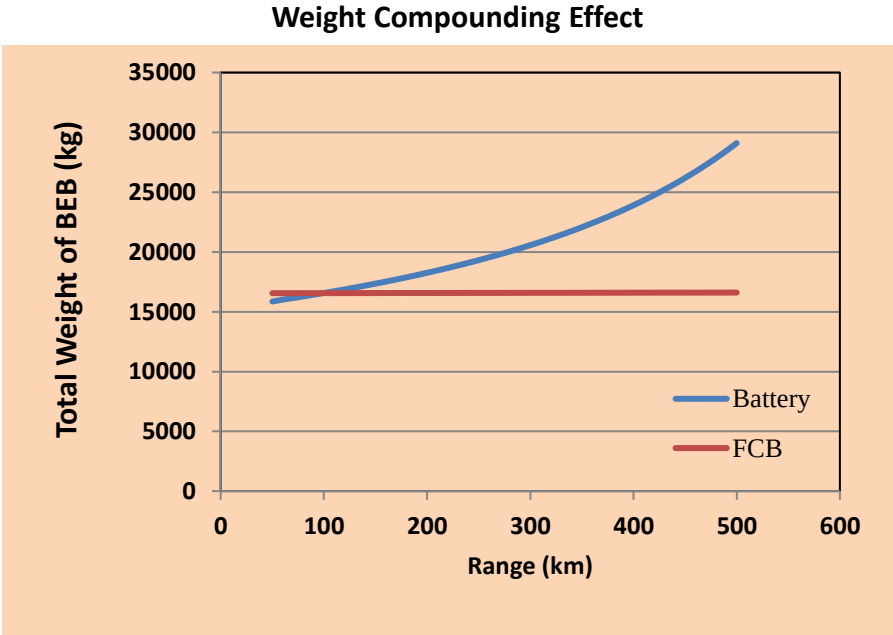
Analysis of CO2e Emissions



Tank to Wheel Energy Comparison



Specific Energy Consumption for Indian conditions based on Indian driving cycle



Weight compounding not an issue with Fuel cell vehicles

GVW of the bus: 15.5 T

Diesel: Well to Wheel Analysis

Well-to-Tank

Crude oil Recovery ~98.6%

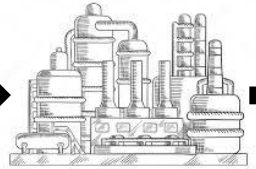
69.3%

15.1%

15.6%

Crude Transport ~1000km

Crude refining 86.2%



25.8%

45.9%

28.3%

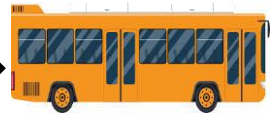
Transportation to bulk terminal (~600km)

Refueling station

83%

Tank-to-Wheels

Pump-to-Wheels 25%



=20.7%

WTT CO2 equivalent emissions- 566 g/km, energy consumed- 4.4 MJ/kWh

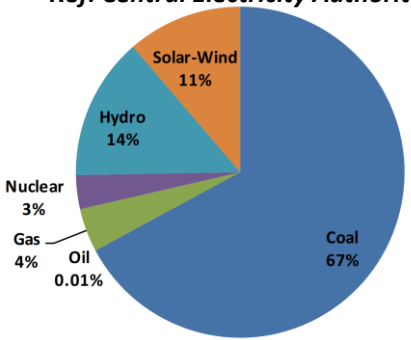
TTW CO2 equivalent emissions- 1613 g/km, energy consumed-14.6 MJ/kWh

WTW Analysis: CO2 equivalent emissions- 2782 g/km
Total Energy Consumed – 17.7 MJ/KWh (17 MJ/Km)

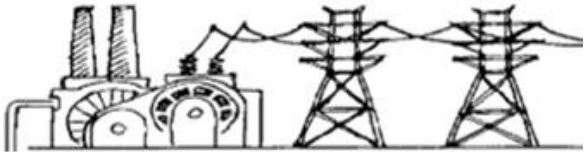
Electricity for Battery Electric Vehicles

India Electricity Generation by fuel-2022

Ref: Central Electricity Authority



Well-to-Tank



Transmission 78%

AC/DC 95%

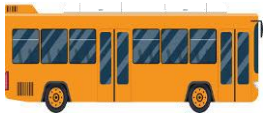
Generation 38%

Charging station

28%

Tank-to-Wheels

72%



Pump-to-Wheels 72%

= 20%

WTT CO_2 equivalent emissions- 3278 g/km, energy consumed- 13 MJ/kWh

TTW CO_2 equivalent emissions (components)- 495 g/km, energy consumed-8.1 MJ/kWh

WTW Analysis: CO_2 equivalent emissions- 1865 g/km
Total Energy Consumed – 21.2 MJ/KWh (21.9 MJ/Km)

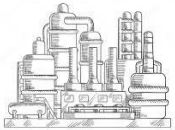
H2 from SMR

Well-to-Tank

NG Recovery ~95.9%

Steam Reforming 71.4%

H2 Refueling station



Pipeline Transport ~2000km

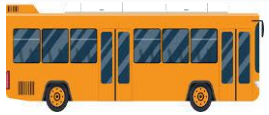
Compression and Transportation (~200km) 90.73%

WTT energy consumed- 8 MJ/kWh, η= 45%

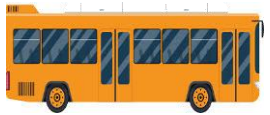
WTT CO2 equivalent emissions- 1418 (2667) g/km

Tank-to-Wheels

H2 for FC
Pump-to-Wheels :46%
WTW :20.7%



H2-ICE
Pump-to-Wheels :25%
WTW: 11.25%



NOx: 60mg/km
CO_2e:18 g/km

TTW CO2 equivalent emissions (components, tailpipe etc)- 127 (145) g/km, energy consumed-8.5 (15) MJ/kWh

WTW Analysis: CO2 equivalent emissions- 1545 (2812) g/km
Total Energy Consumed – 18.1 (32.6) MJ/KWh or 17.2 (31.3) MJ/Km

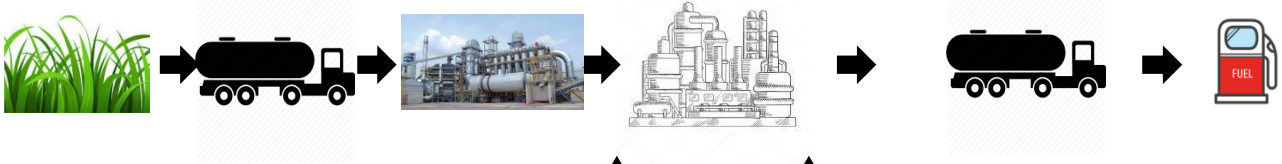
H2 from Biomass gasification

Well-to-Tank

Drying and handling
~80%

Air gasification
48%

H2 Refueling station



Truck Transport
~200km

O_2

Steam

Oxy-steam gasification
59%

Compression and Transportation (~200km)
90.73%

Tank-to-Wheels

H2 for FC
Pump-to-Wheels :46%
WTW: 15.2% (18.86%)

H2-ICE
Pump-to-Wheels :25%
WTW: 10.25% (8.25%)

NOx: 60mg/km
CO_2e:18 g/km

TTW CO2 equivalent emissions (components, tailpipe etc)- 127 (145) g/km, energy consumed-8.5 (15) MJ/kWh

WTT energy consumed- 11 MJ/kWh, η=Oxy-Steam:41% AND Air: 33%

WTT CO2 equivalent emissions- 1114 g/km (-2096)

WTW Analysis: CO2 equivalent emissions -988 (-1951) g/km
Total Energy Consumed – 24.6 (44.6) MJ/KWh or 23.2 (42.5) MJ/Km

Solar PV based H2

Well-to-Tank

Solar PV with Mfg 75%

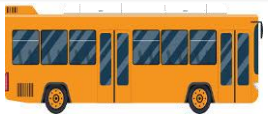
PEM electrolysis 72%

H2 Refueling station

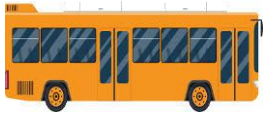
Compression and Transportation (~200km) 90.73%

Tank-to-Wheels

H2 for FC
Pump-to-Wheels:46%
WTW: 24.8%



H2-ICE
Pump-to-Wheels :25%
WTW: 13.5%



NOx: 60mg/km
CO_2e:18 g/km

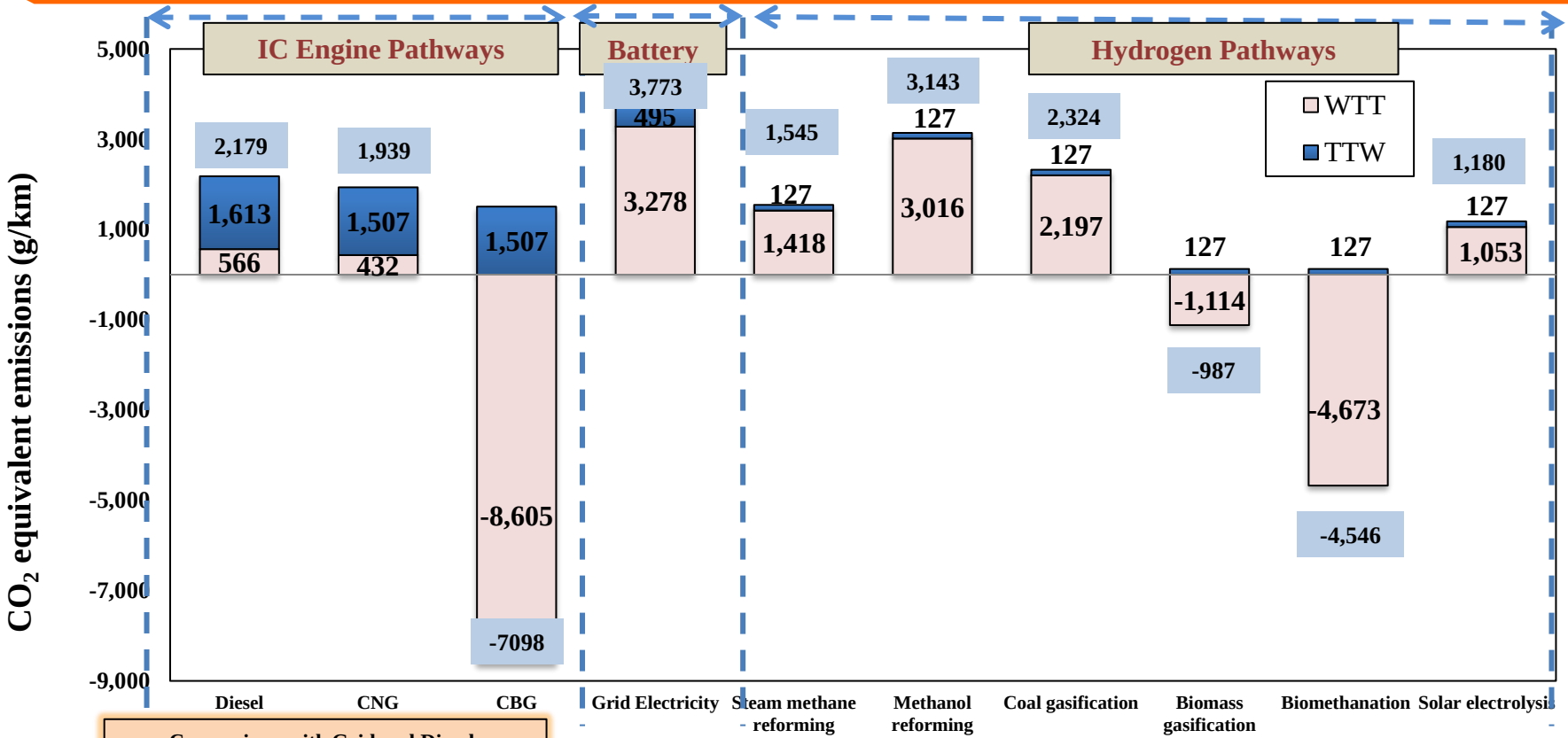
WTT energy consumed- 6.6 MJ/kWh, η=54%

WTT CO2 equivalent emissions- 1053 (1981) g/km

TTW CO2 equivalent emissions (components, tailpipe etc)- 127 (145) g/km, energy consumed-8.5 (15) MJ/kWh

WTW Analysis: CO2 equivalent emissions- 1180 (2126) g/km
Total Energy Consumed – 15 (27) MJ/KWh or 14.4 (26) MJ/Km

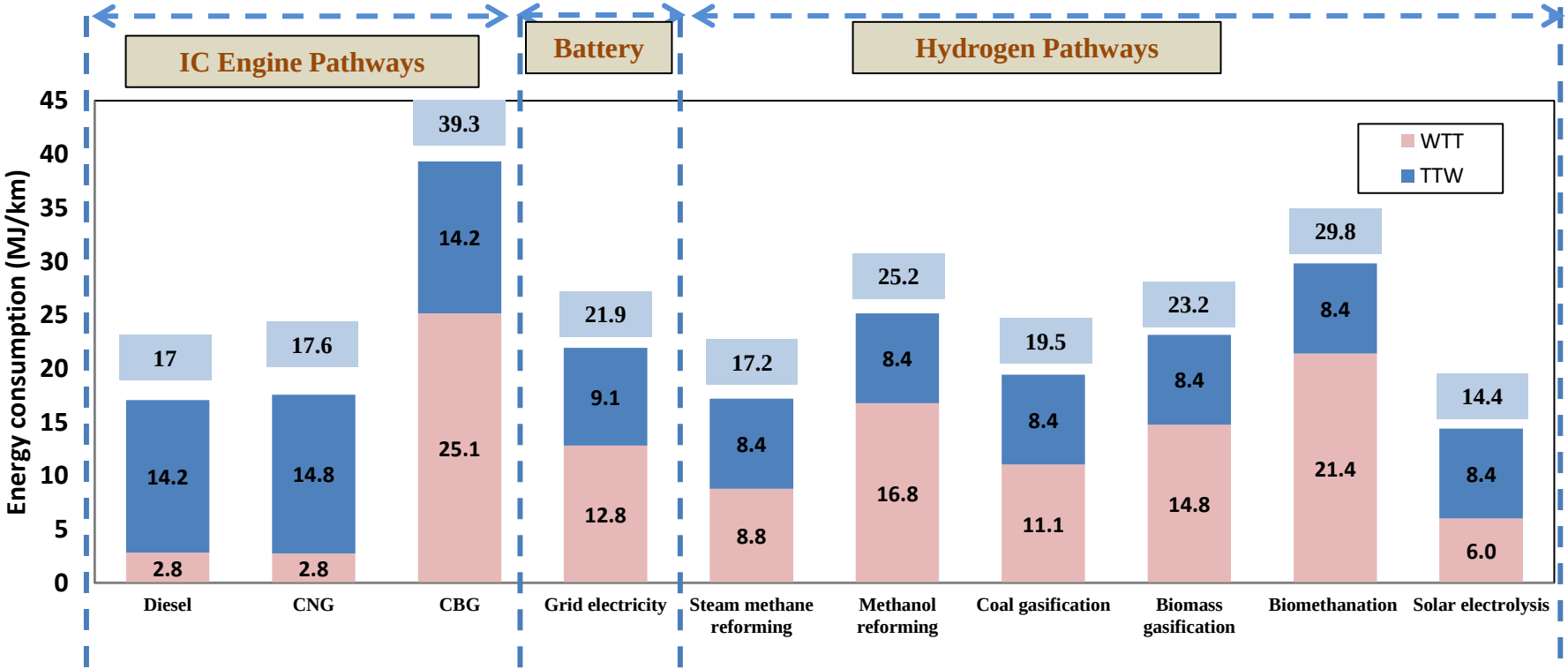
GHG emissions: Well to Wheel



Comparison with Grid and Diesel:
SMR : 60% and 30% less
Biomass based pathways: Net Negative
Solar based Hydrogen: 68% and 45% less

Oxy-steam biomass gasification WTT: -1143 g/km TTW: 127 g/km; Total -1017 g/km

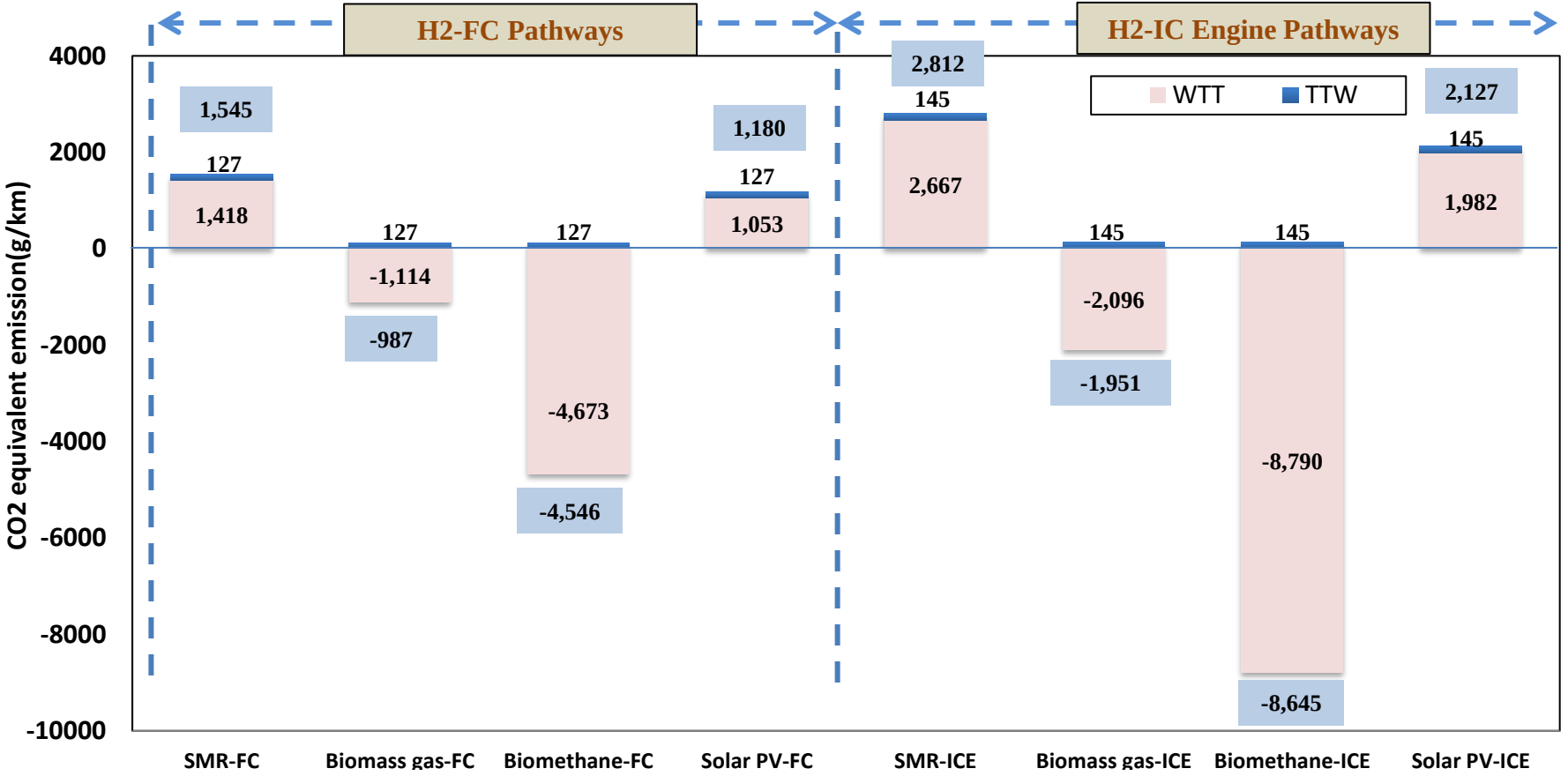
Energy Consumption: Well to Wheel



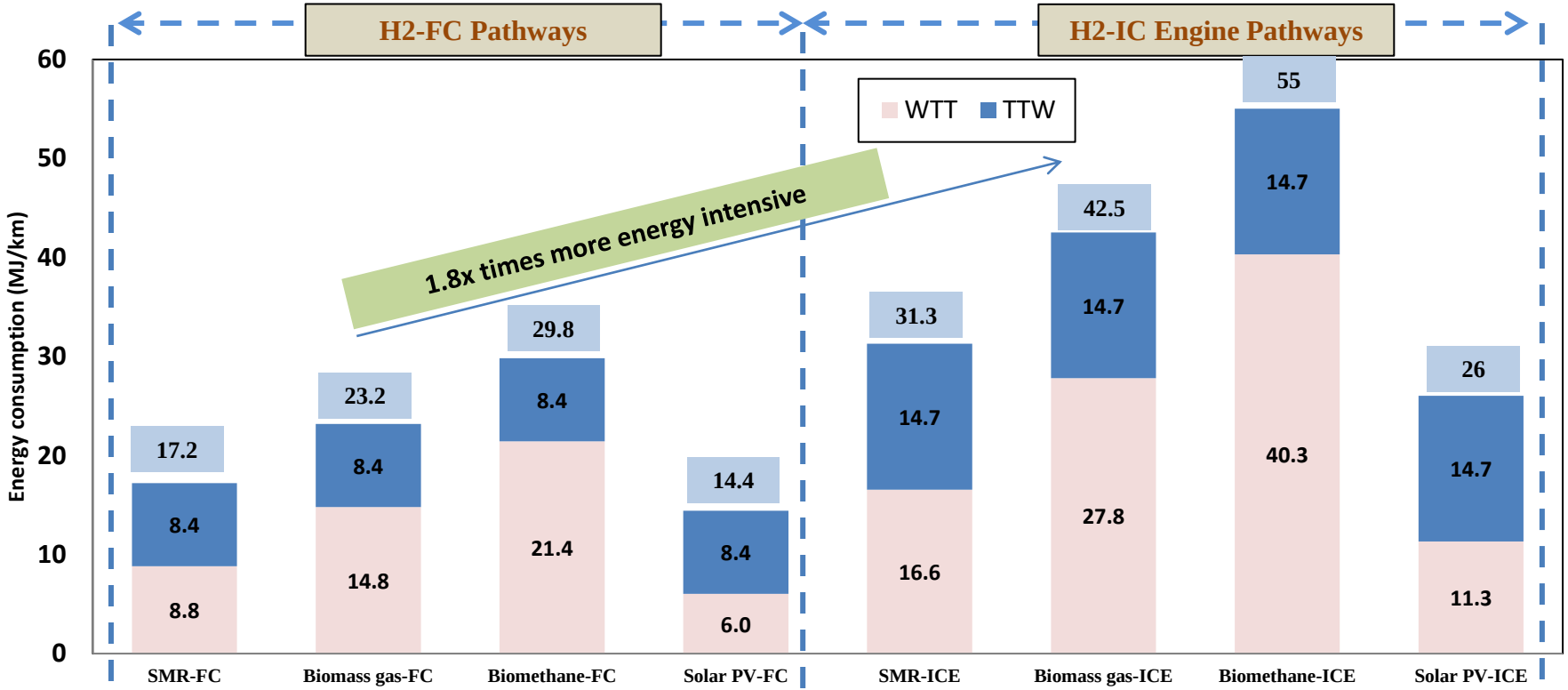
Comparison with Grid and Diesel:
SMR : 21% and almost same
Solar based Hydrogen: 34% and 15% less

Oxy-steam biomass gasification
WTT:10.2 MJ/km T
TW: 8.4 MJ/km; Total 18.6 MJ/km

GHG emissions: FC vs ICE



Energy consumption: FC vs ICE



Conclusion

01

Color shall be identified with CO_2 emissions of the process

02

WTT CO2 emissions and energy consumption of the pathway – needs proper consideration

03

An energy comparator may be proposed to provide level playing field for different pathways

04

Powertrain technology may be assessed based on TTW efficiency and overall energy penalties


Thank
you