Powertrain configurations with fuel cells for different vehicles niches

Hans Pohl - project leader — Viktoria Swedish ICT

Anders Grauers — Svenskt El och Hybridfordonscentrum

Erik Wiberg — Vätgas Sverige

Joakim Nyman — Viktoria Swedish ICT

Summary

This project: - Compile database of existing Fuel cell vehicles

- Basic TCO analysis for different vehicle niches

Some findings:

- Method provide important insights on FC powertrains niches but more analysis needed for final answers.
- FCEV & BEV have radically different cost structures
  ⇒ Aims for different niches
- High battery utilization necessary for BEV to be cheaper than FCEV. Private cars with big battery cannot get high battery utilization.
- FC REX seems more interesting for cars than FCEV.

Compared alternatives

FCEV	Fuel Cell Electric Vehicle **on Hydrogen**
BEV	Battery Electric Vehicle
FC REX	Fuel Cell Range Extender **on Hydrogen**
ICE REX	Comb. Engine Range Extender **on Biofuel**
ICE	Combustion Engine **on Biofuel** (not fossil diesel!)

SCOPE OF STUDY

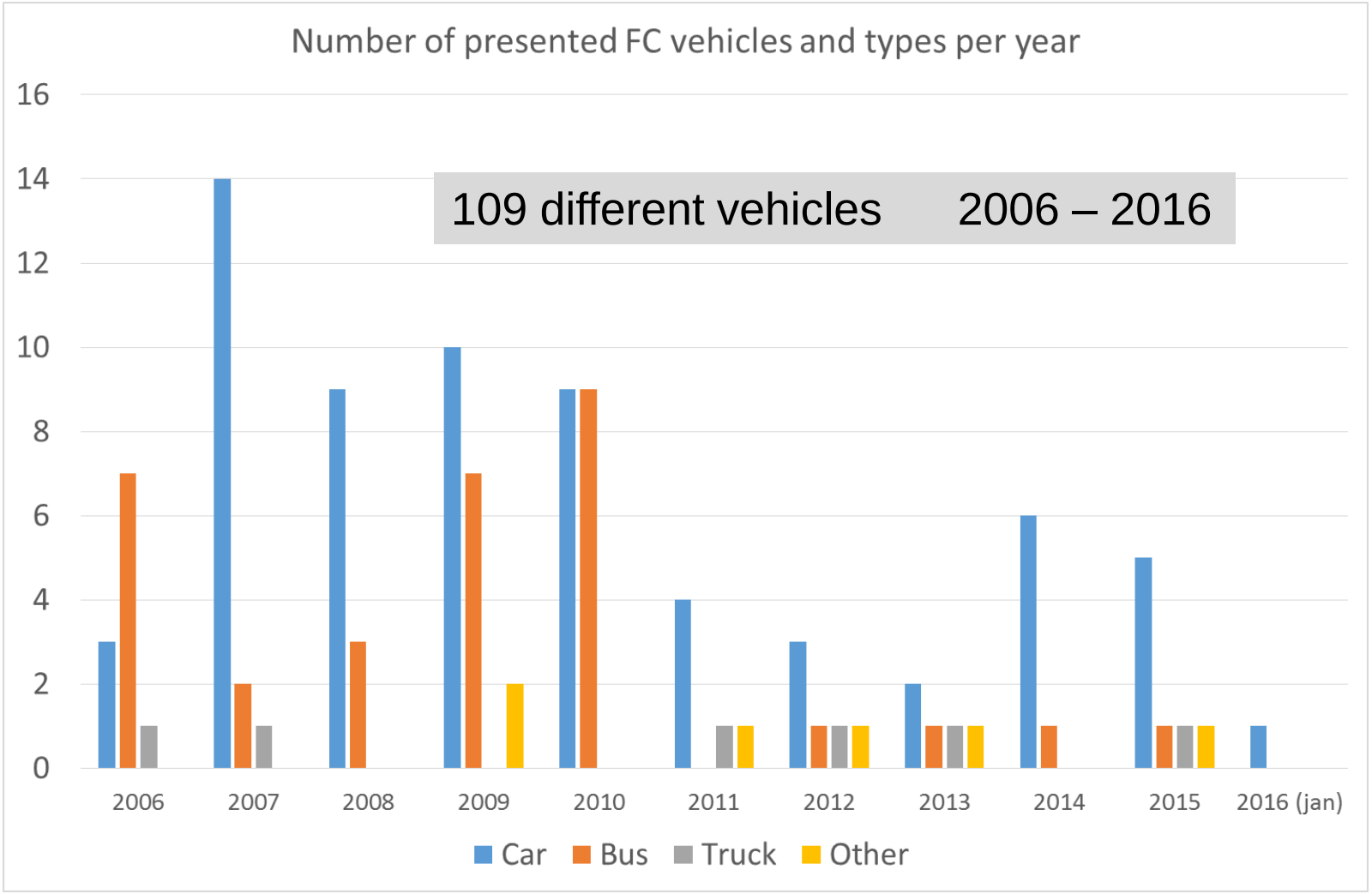
A study of existing and possible combinations of fuel cells and other energy converters in vehicles:

- What exists on the road?
- How are different solutions positioned on the market?
- How do the powertrains for buses and cars differ?
- What are the prospects for different powertrains in different applications and use patterns?

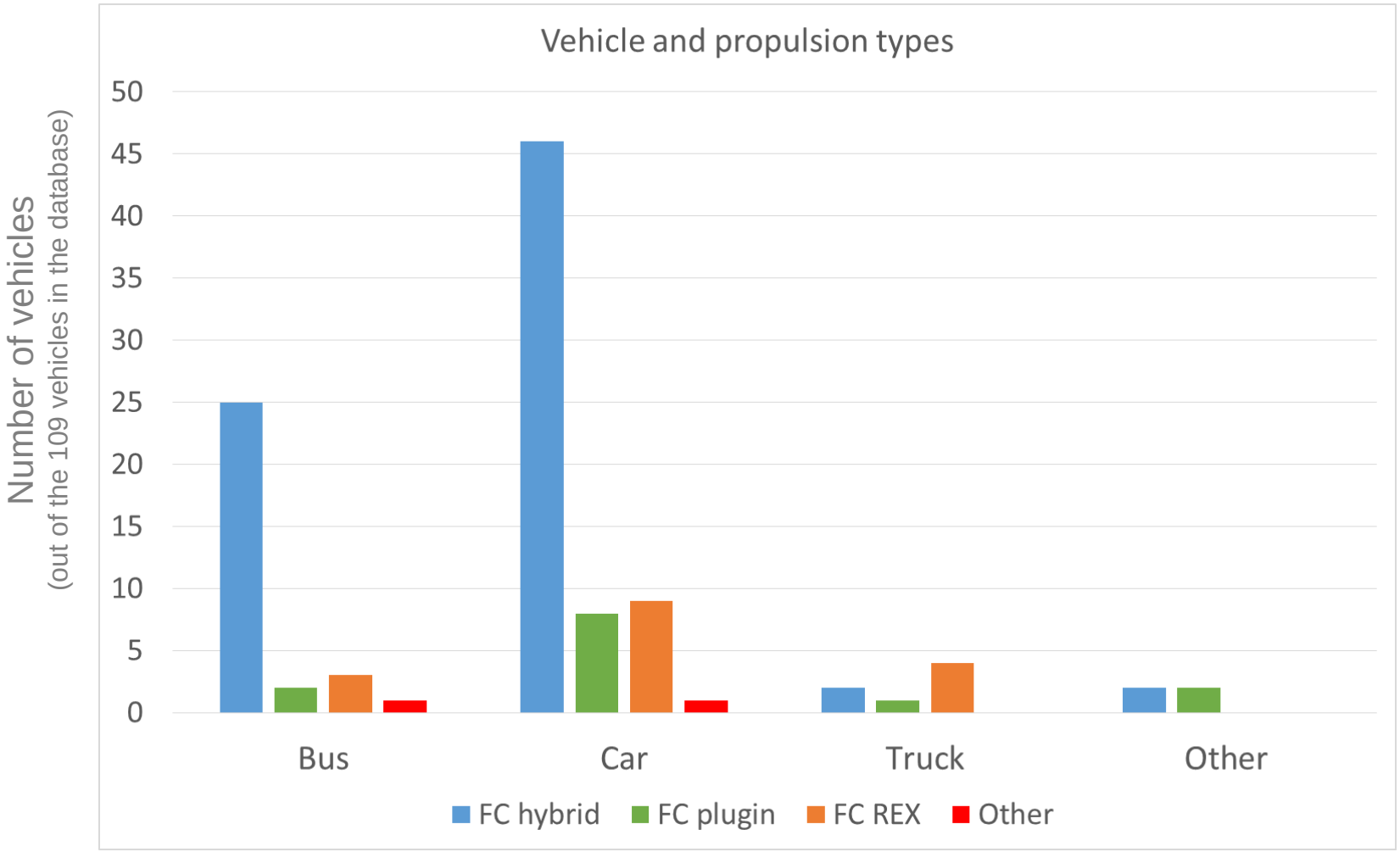
Project leader: Hans Pohl, Viktoria Swedish ICT AB.
Participants: Anders Grauers, Chalmers/SHC; Erik Wiberg, Vätgas Sverige and Joakim Nyman, Viktoria Swedish ICT.

Budget 300 kSEK.

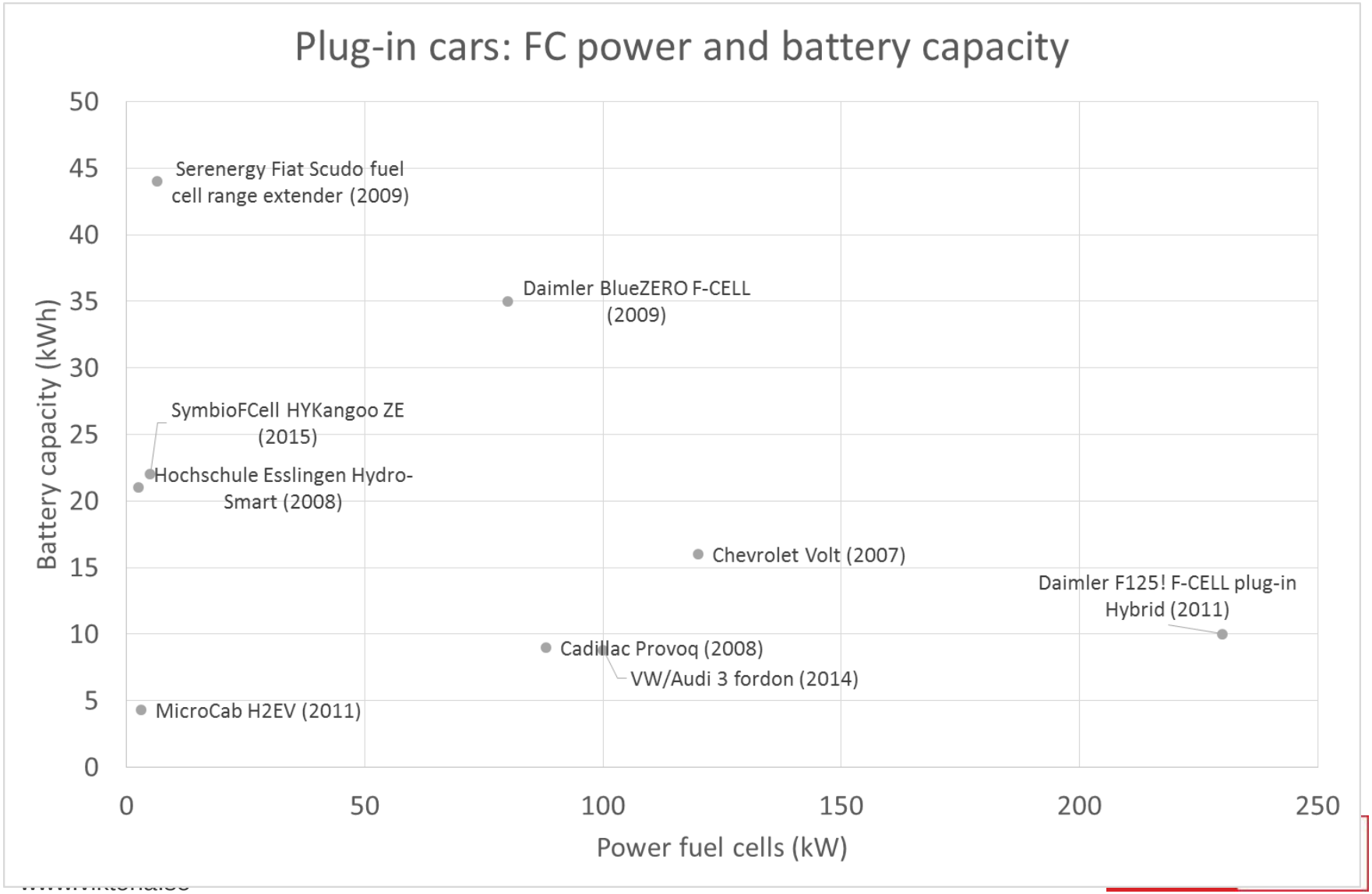
FC VEHICLE TYPES PER YEAR



FC VEHICLE PROPULSION TYPES



PLUGIN: FC POWER & BATTERY CAPACITY



CONCLUSIONS: DATABASE STUDY

- Wide range of propulsion types presented
  - Several concept vehicles may explain the large variations in propulsion types

- No clear trends but:
  - FC hybrid propulsion dominates heavily for cars and buses
  - FC hybrid propulsion dominates even more among produced vehicles

TCO Cost model

Powertrain

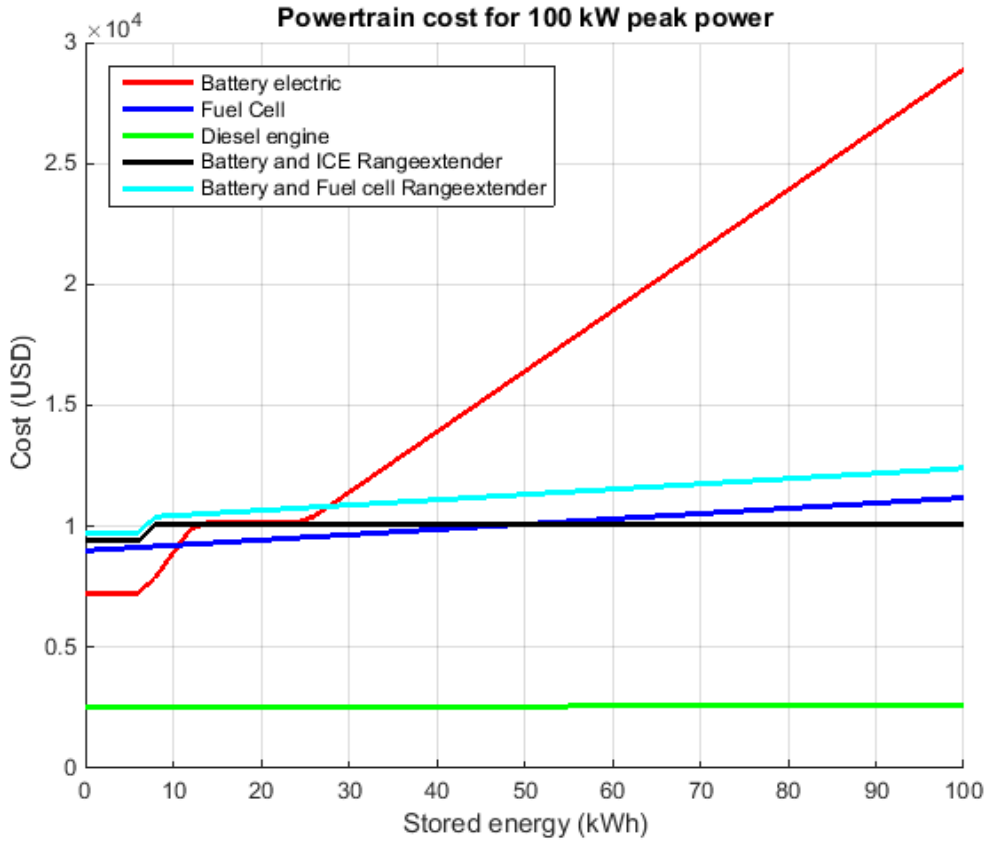
+ Energy storage/Tank

+ ”Fuel” cost during life

Not included:

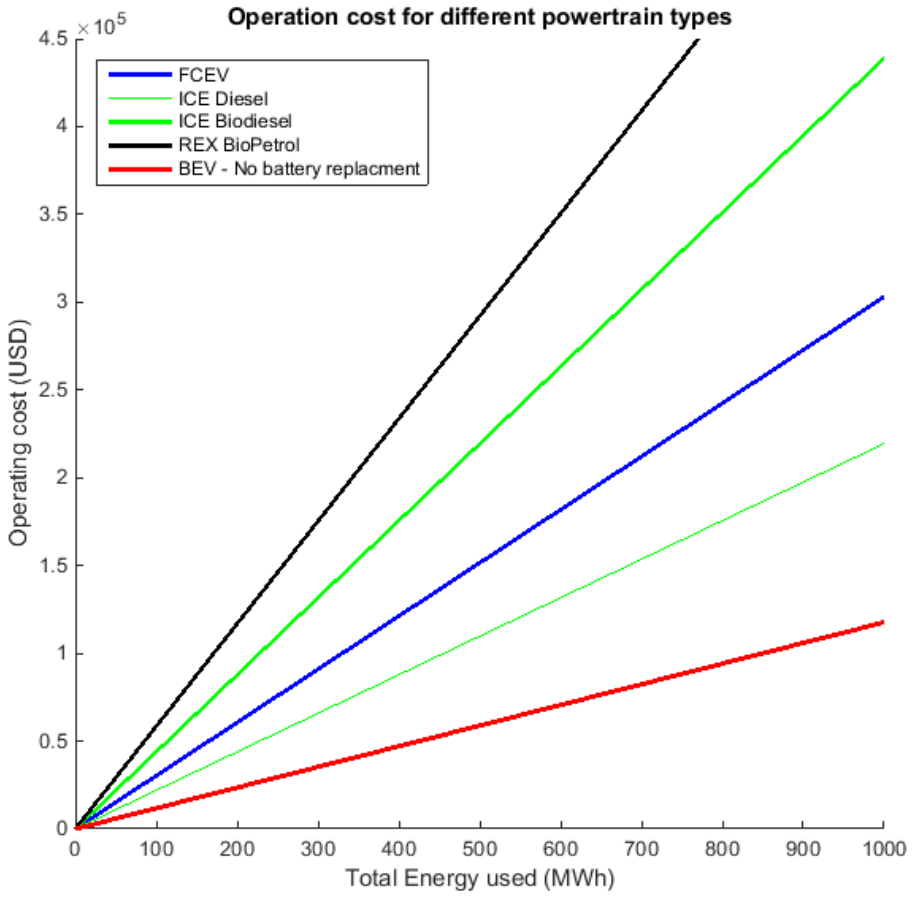
- Taxes and external costs
- Cost for public charging infrastructure for BEVs
- Maintenance costs

Powertrain cost



- BEV expensive, especially for large energy storage.
- FCEV mostly cheaper than BEV
- ICE by far the cheapest
- ICE REX cheaper than BEV if battery > 25 kWh
- FC REX only a little more expensive than ICE REX

”Fuel” cost – ”Tank” to Wheel



- Electricity cheapest

Cost increase factor compared to electricity:

- Diesel 1.8
- H_2 2.5
- Bio Diesel 3.7
- Bio Petrol 5.0

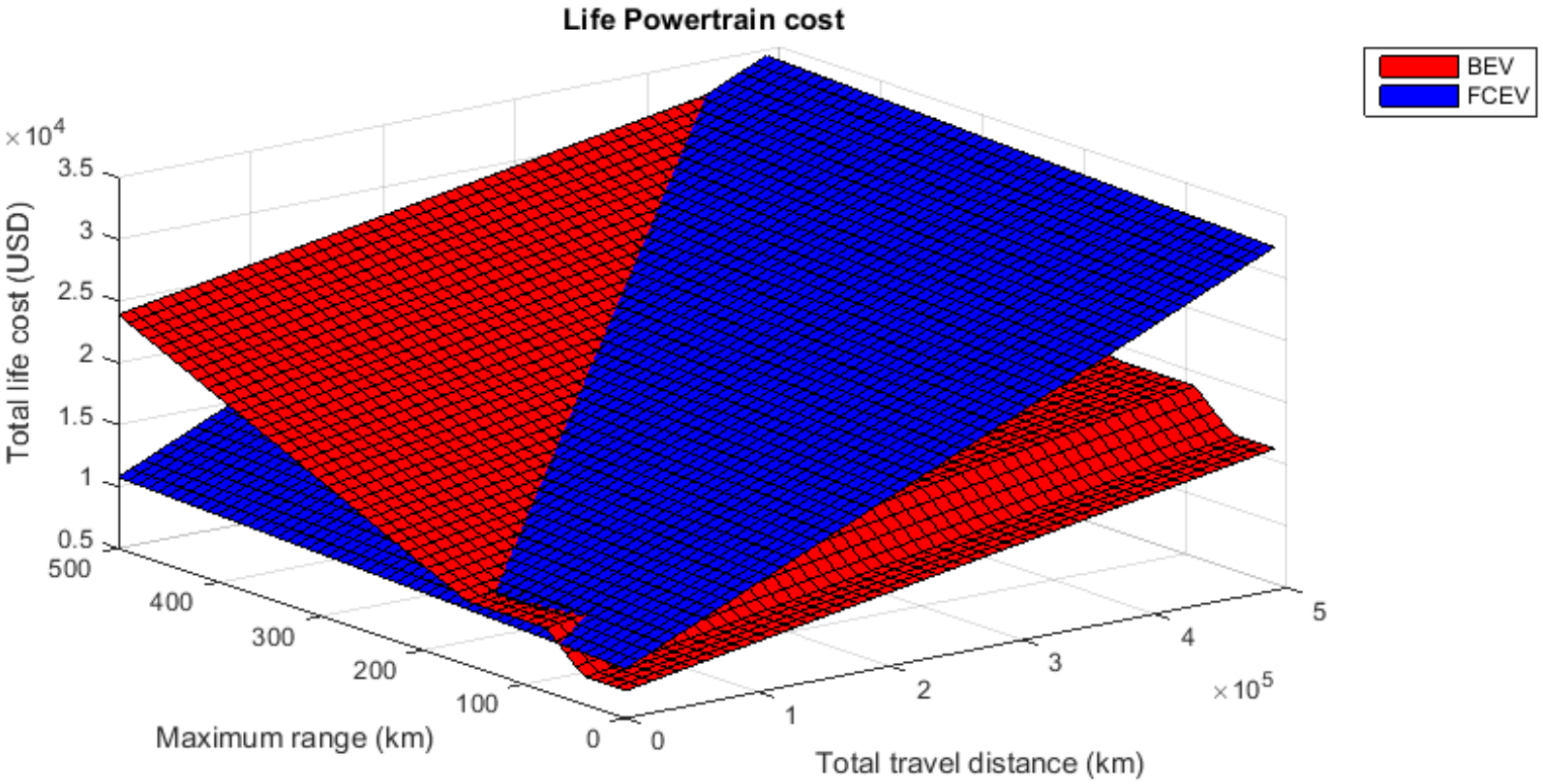
Without tax!

Step 1:

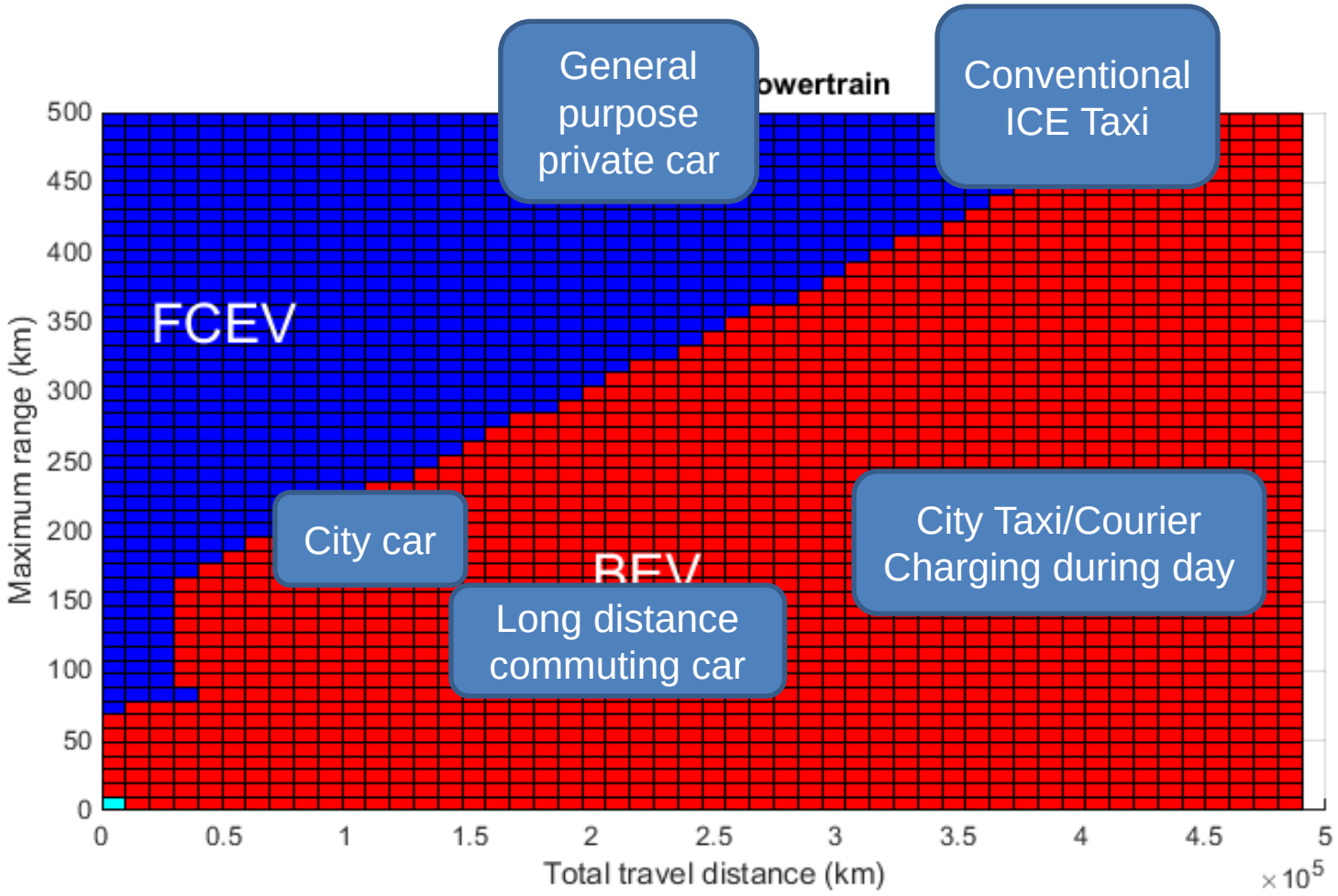
TCO comparison
if battery lasts forever!

Lowest TCO for different segments

only FCEV versus BEV (one battery)

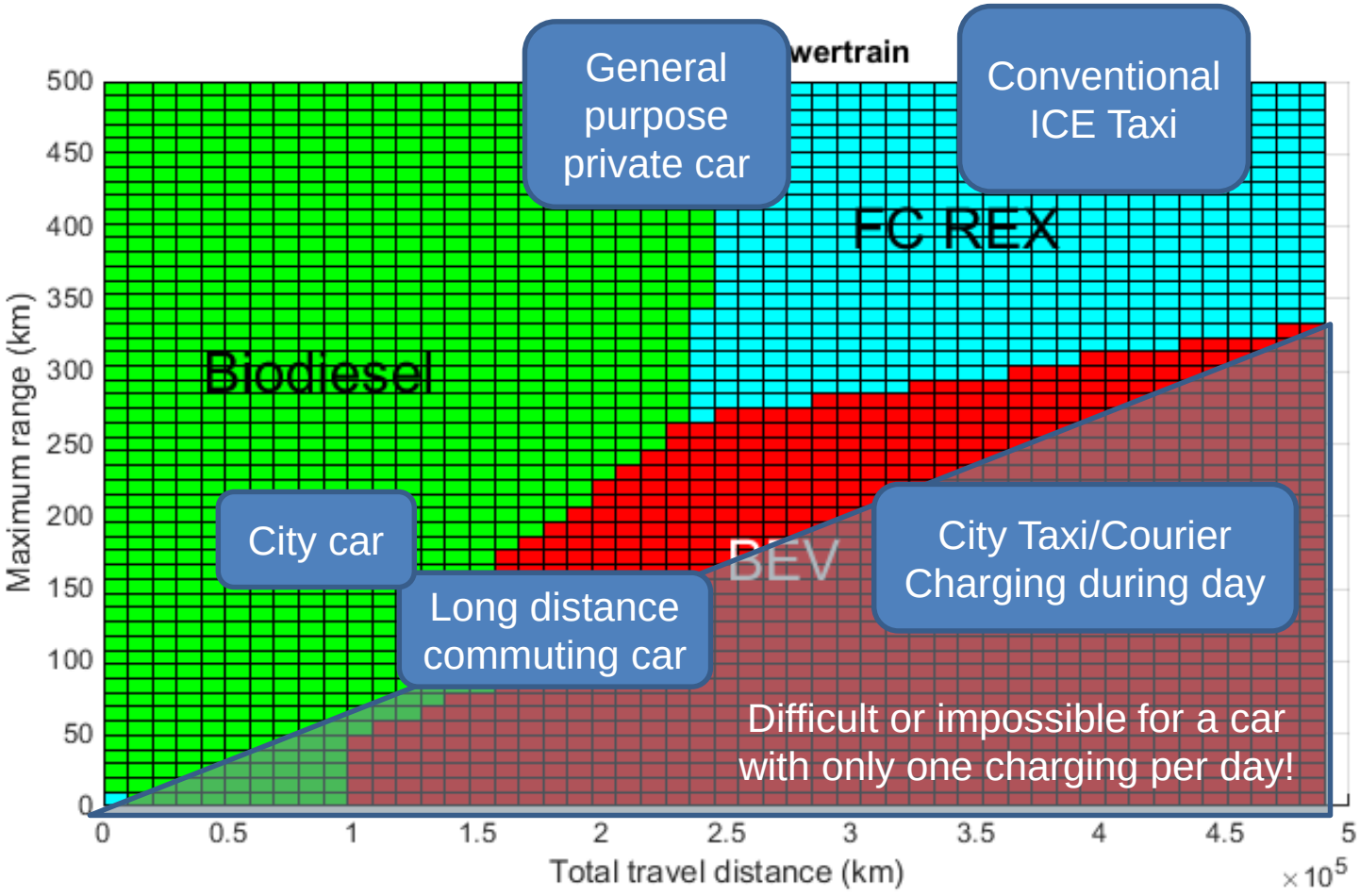


Lowest TCO for different segments



Lowest TCO for different segments

REX vehicles run 67% on battery + 33% on REX



FC REX has lower”fuel” cost than FCEV

Step 2:

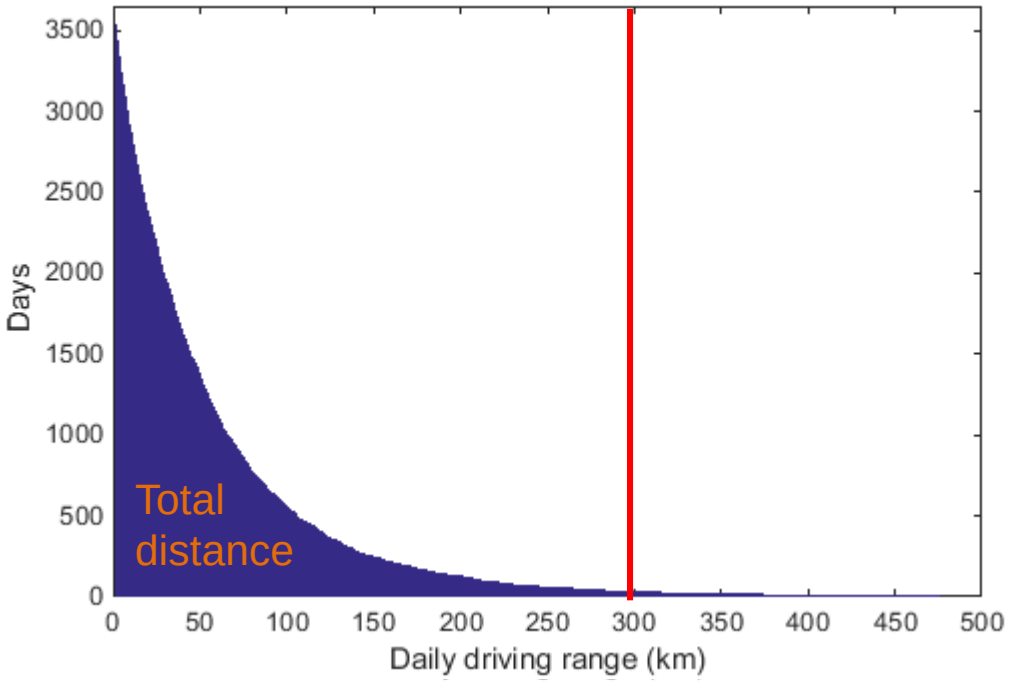
TCO comparison with limited battery life length.

Battery use – private car

10 years
Varying daily driving

Sort in descending order
Battery sized for 300 km range

Average	50 km/day
Total	200’000 km



Battery utilization = total distance / Range on a full battery

In this case ⇒ 667 full cycles

Battery poorly used in private cars!

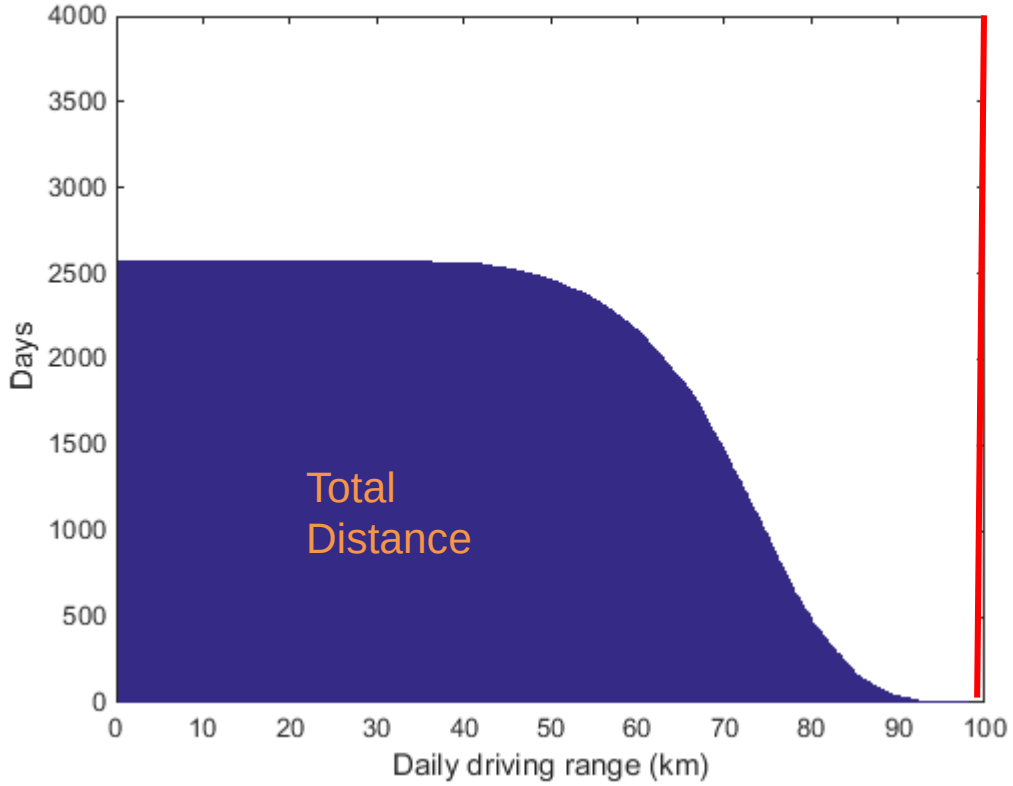
Battery use – Commuting car

10 year almost constant range
5 days per week

Needs 100 km battery range for this use

Sort in descending order

Average	70 km/day
Total	180’000 km



Battery utilization = total distance / Range on a full battery

In this case ⟹ 1800 full cycles

Hard to utilize battery better than this in a private car!

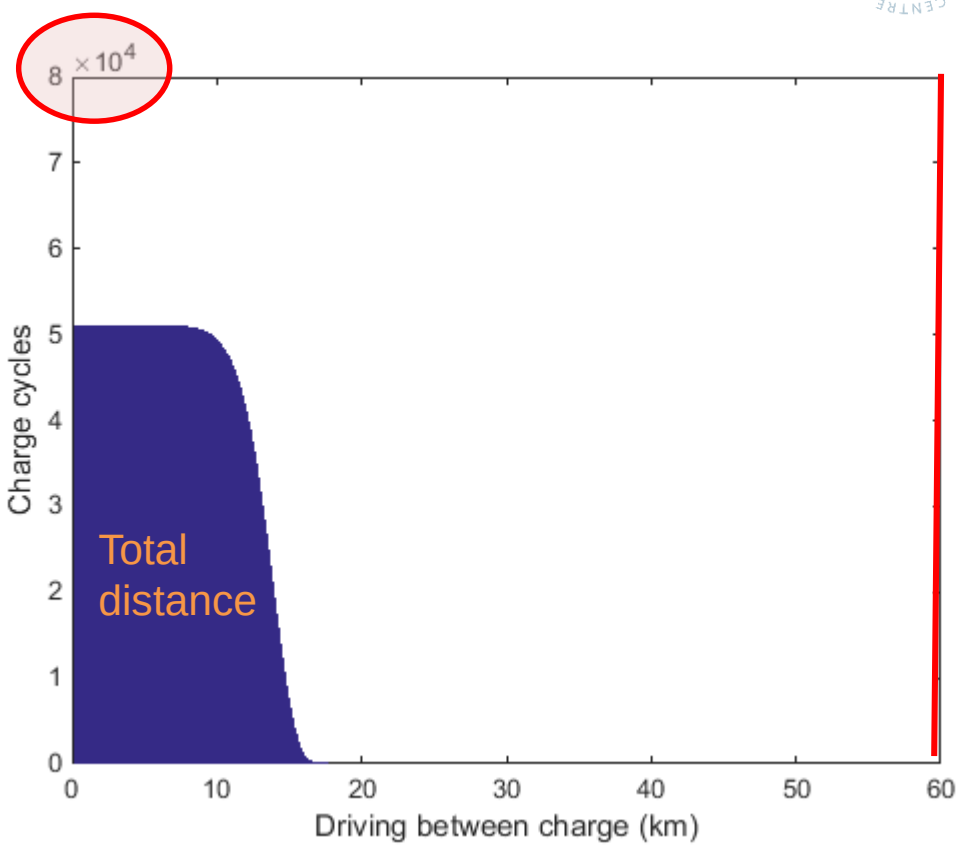
Bus with end stop charging

10 year almost constant range

5 days per week
20 charges per day

Needs 60 km battery range
for this use

Average	15 km/cycle
Total	800’000 km

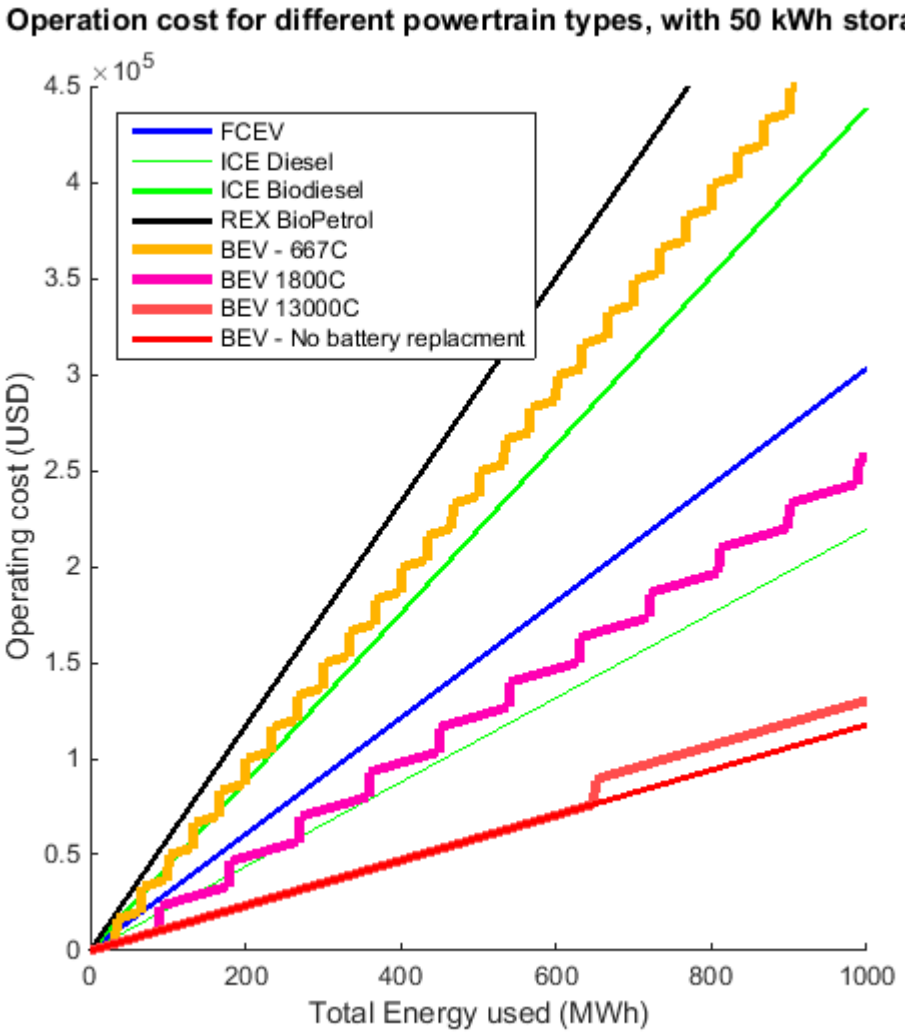


Battery utilization = total distance / Range on a full battery

In this case ⇒ 13’000 full cycles

This bus use its battery 20 more than a private car!

Fuel cost - With battery replacement

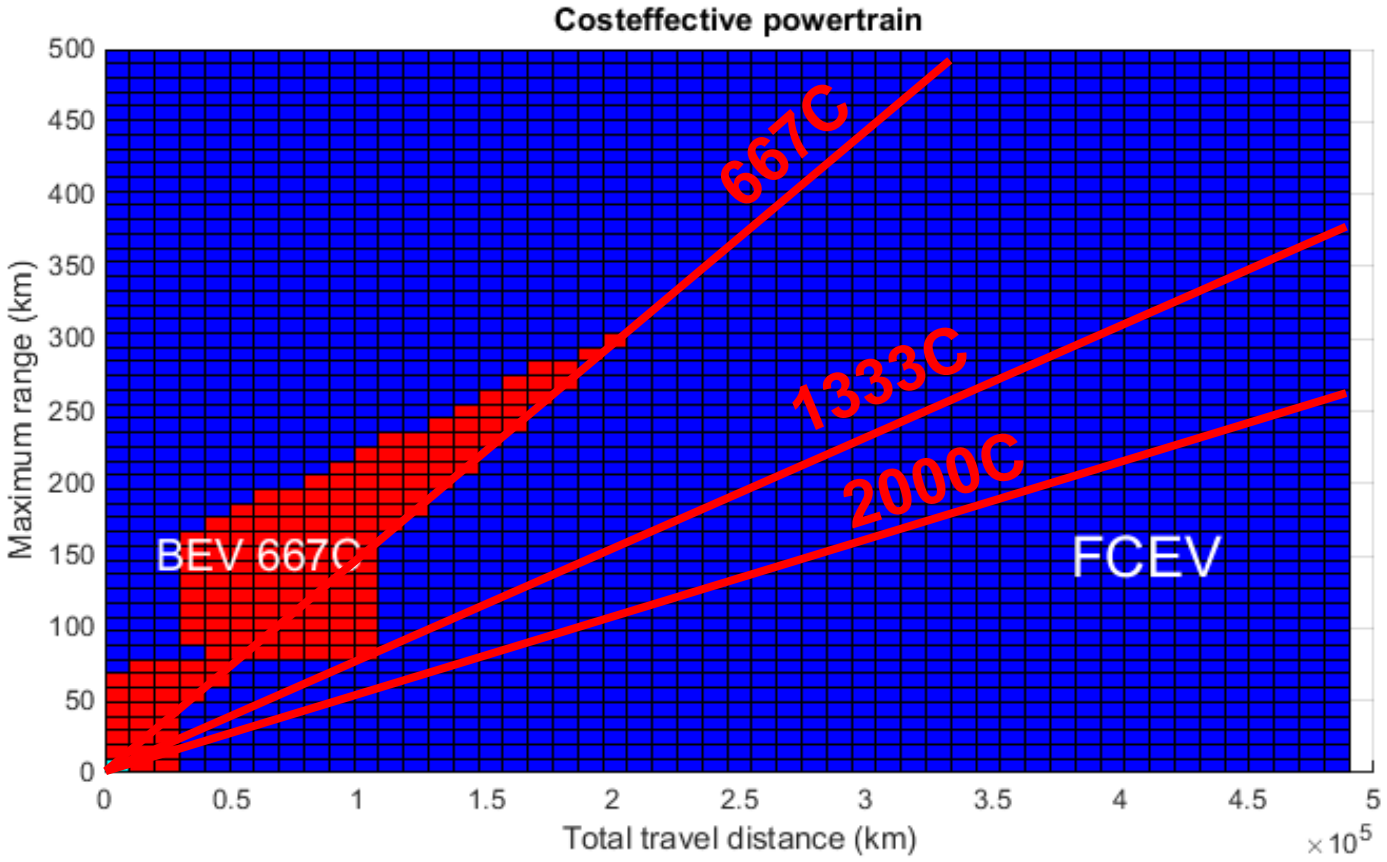


- 667C very high operating cost
- 1800C almost the same cost as Fuel cell
- 13000C leads to very low cost

Lowest TCO for different segments

only FCEV versus BEV (incl battery replacment)

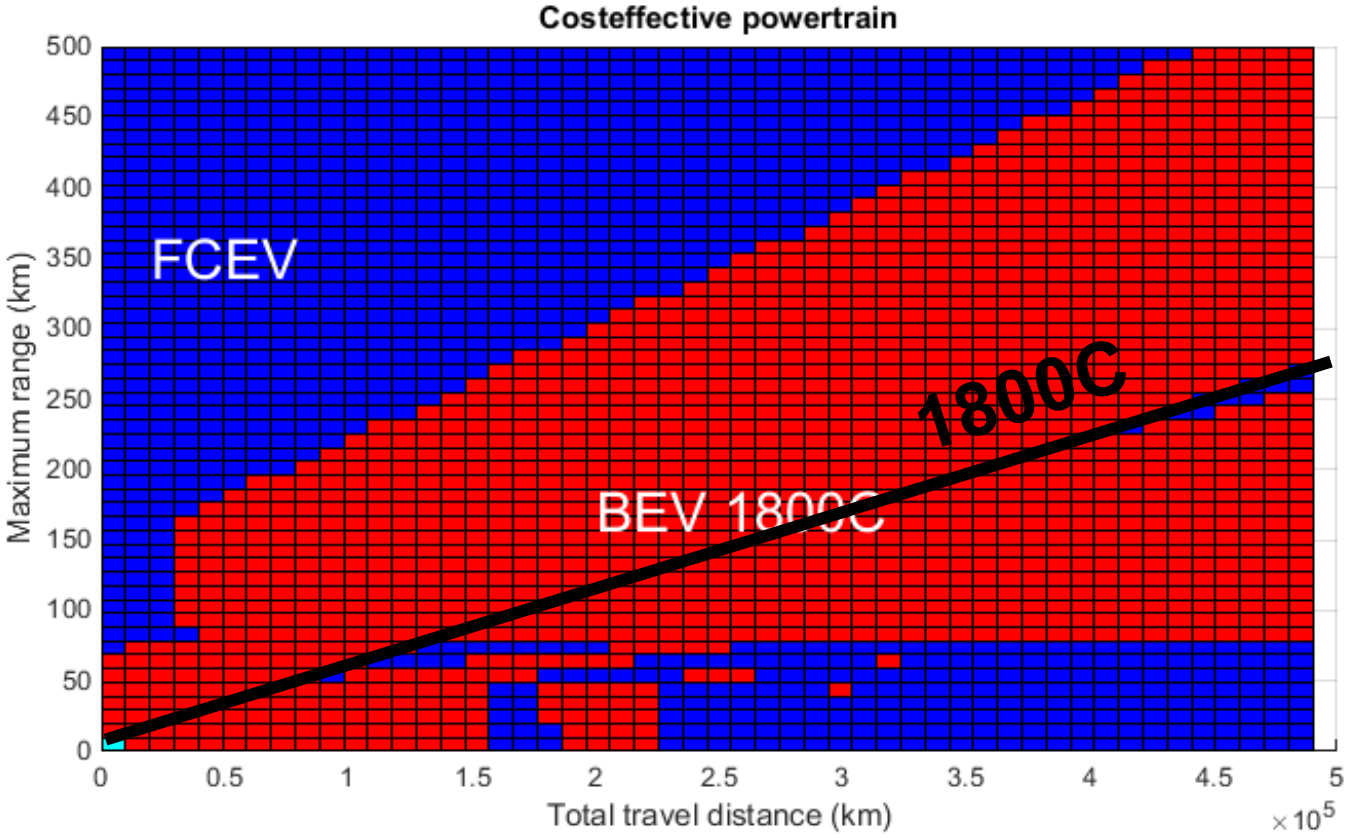
Battery utilization 667C



Lowest TCO for different segments

only FCEV versus BEV (incl battery replacment)

Battery utilization 1800C



Summary

This project: - Compile database of existing Fuel cell vehicles

- Basic TCO analysis for different vehicle niches

Some findings:

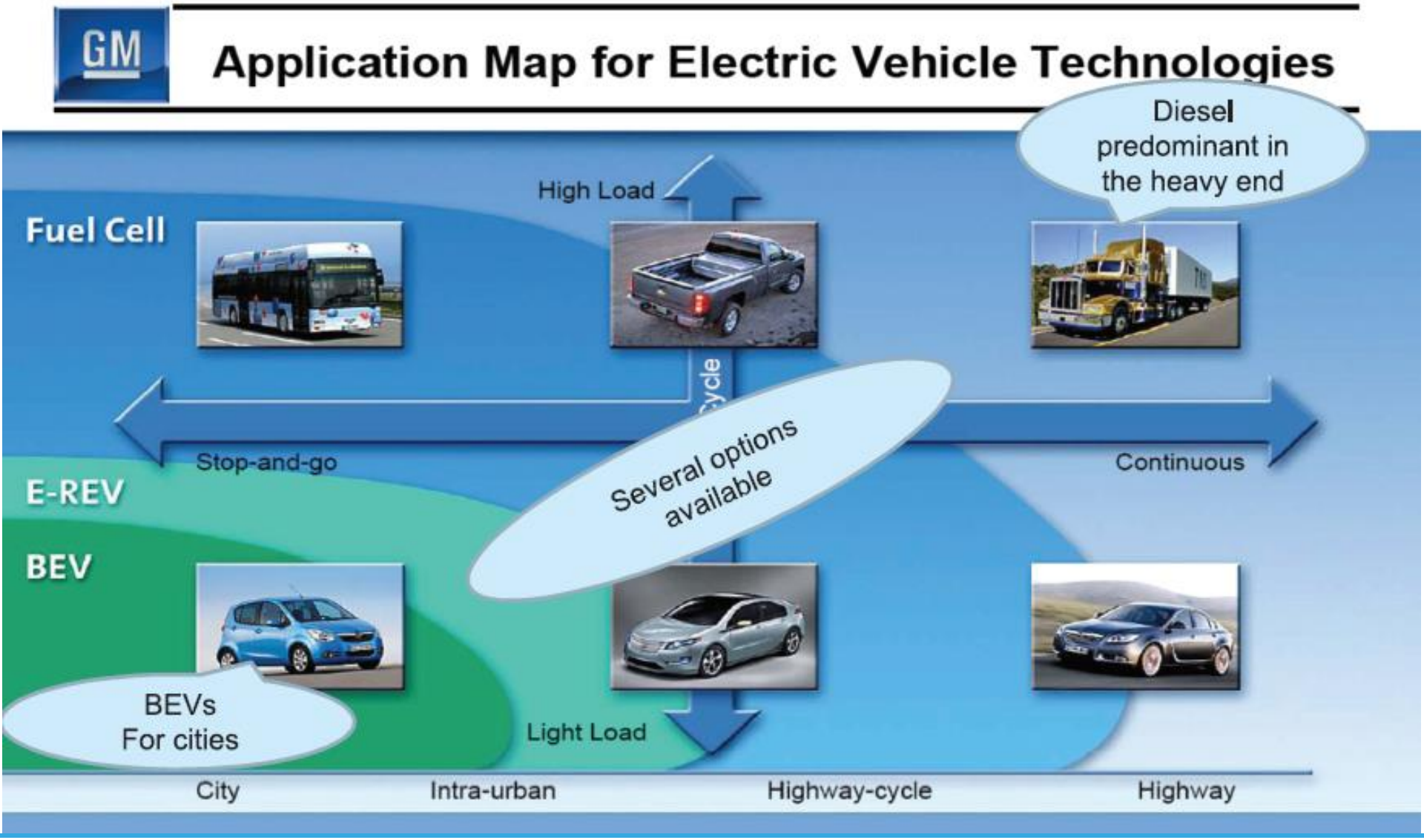
- Method provide important insights on FC powertrains niches but more analysis needed for final answers.
- FCEV & BEV have radically different cost structures
  ⇒ Aims for different niches
- High battery utilization necessary for BEV to be cheaper than FCEV. Private cars with big battery cannot get high battery utilization.
- FC REX seems more interesting for cars than FCEV.

Thanks!

SCANIA VOLVO VOLVO Energimyndigheten

LUND UNIVERSITY CHALMERS KTH VETENSKAP OCH KONST LINKÖPINGS UNIVERSITET UPPSALA UNIVERSITET

Partly different niches than GM



Cost for different performance req´s

	Marginal cost for Power	Marginal cost for Stored Energy (~Range)
ICE diesel (mild hybrid)	15 USD/kW **	0.4 USD/kWh
Electr. propulsion + Fuel Cell	35 + 40 USD/kW	18 USD/kWh*
Electr. propulsion + Battery	35 + 0 USD/kW for a big energy storage 35+40 USD/kW for a small energy storage	250 USD/kWh* (500 USD/kWh*) Power optimized batteries

*) kWh which can be delivered to propulsion motor after losses – Not equal to the energy stored in the tank/battery.

**) 1 kW from an ICE have lower value for the driver than 1 kW from an electric propulsion motor.

Power optimized battery cost about the same per kW as a Fuel cell!

”Fuel” cost – ”Tank” to Wheel

Electricity for BEV: el from grid 0.085 USD/kWh.
After Charge and Discharge Losses. ⇒ **0.12 USD/KWh**

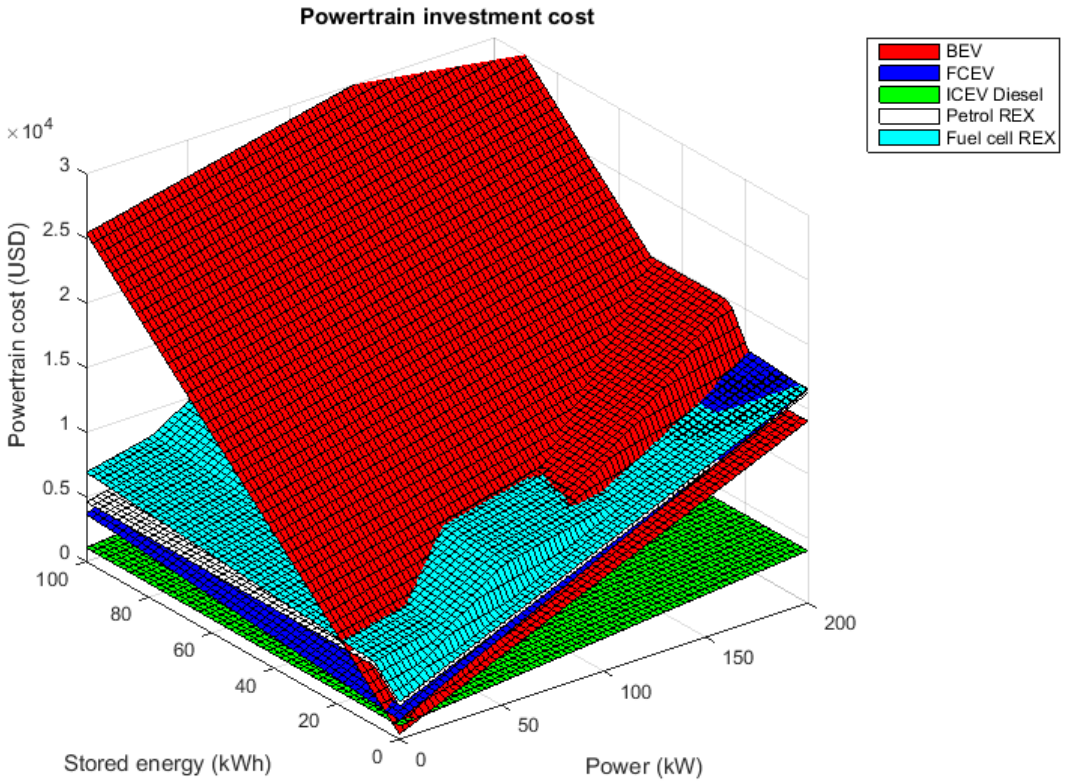
Diesel: 0.7 USD/l (6 SEK/l) ⇒ **0.22 USD/kWh**
After ICE and driveline losses

Hydrogen: 5 USD/kg
After Fuel Cell lossed ⇒ **0.30 USD/kWh**

Biodiesel: 1.4 USD/l (12 SEK/l)
After ICE and driveline losses ⇒ **0.44 USD/kWh**

Biopetrol: 1.4 USD/l (12 SEK/l)
After ICE and driveline losses ⇒ **0.60 USD/kWh**

Powertrain cost

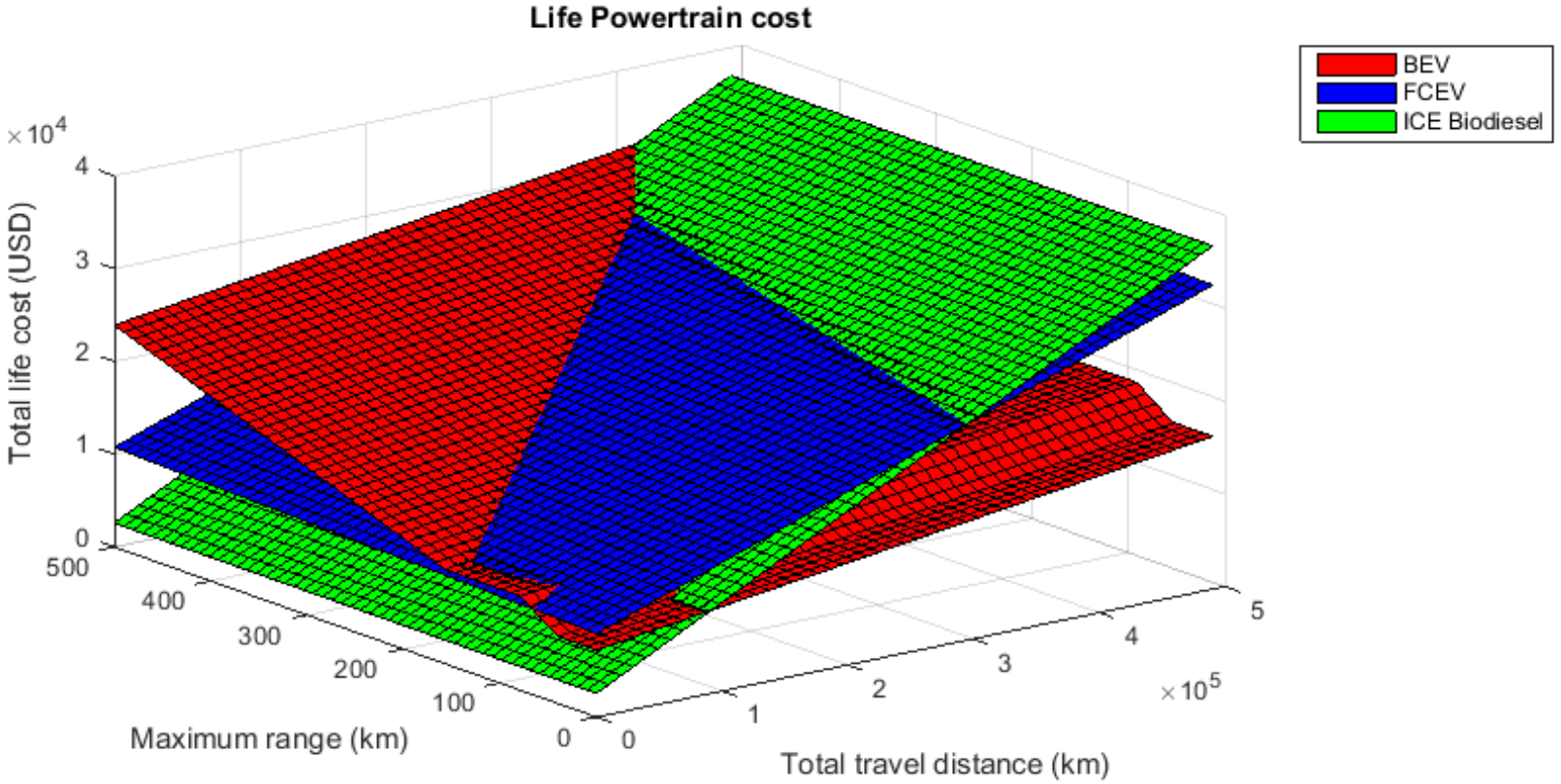


Parameters:

- **Power**
- **Stored Energy**

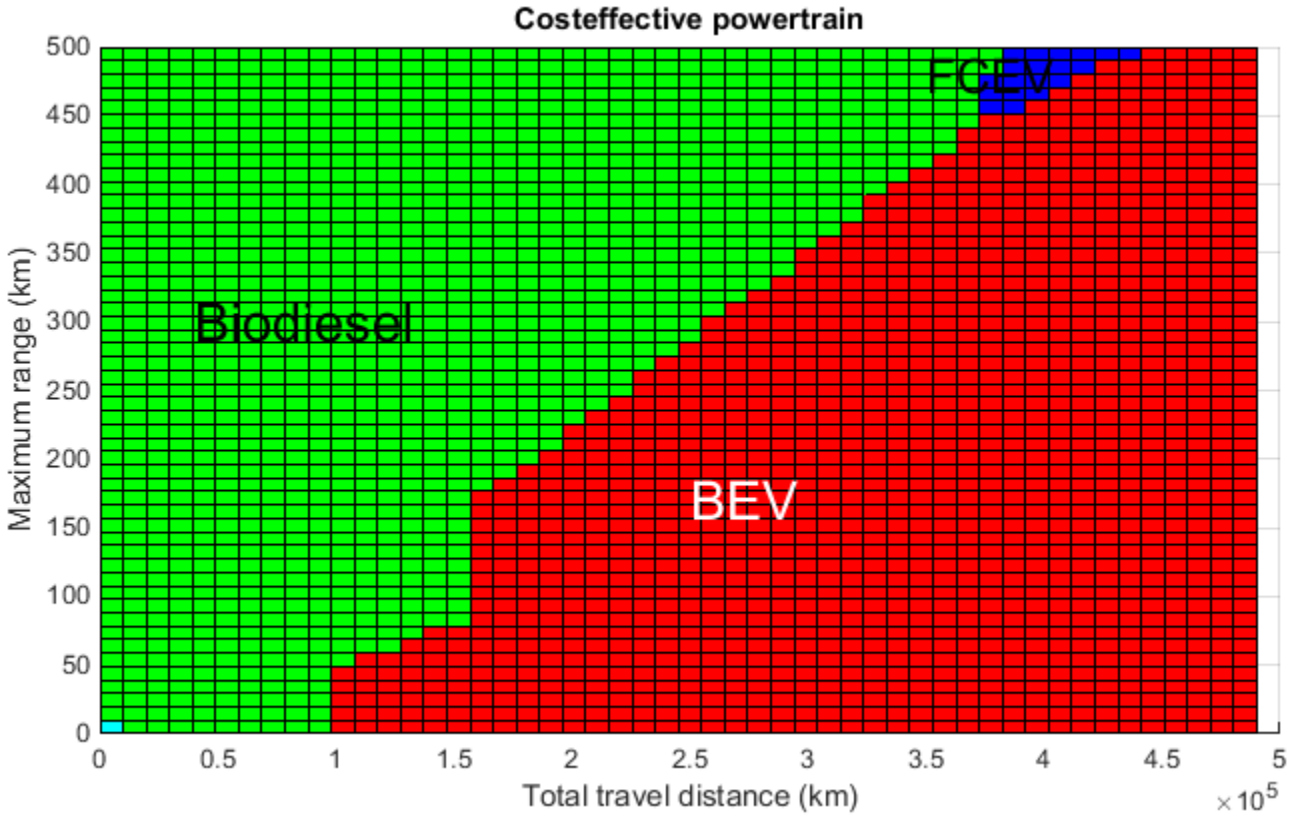
Lowest TCO for different segments

only FCEV versus BEV (one battery) and ICE Biodiesel



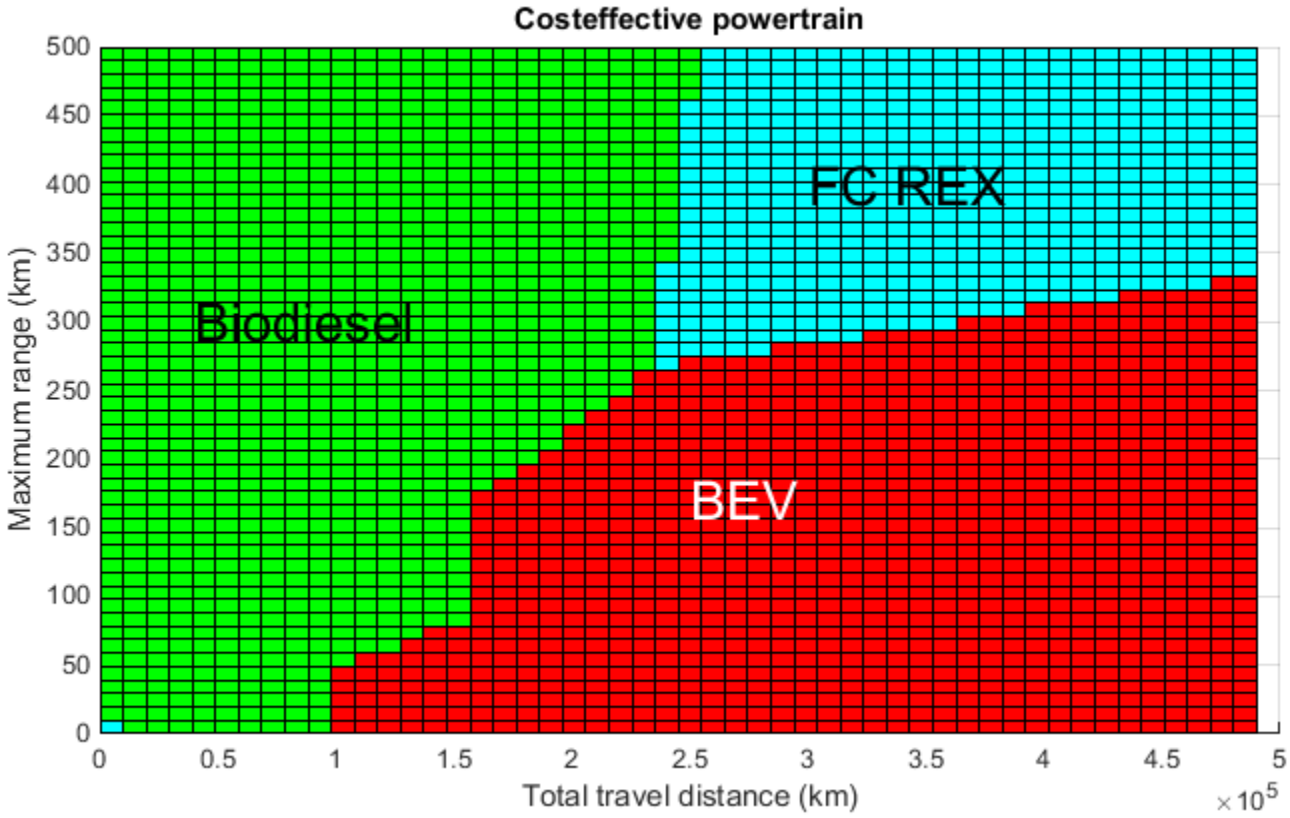
Lowest TCO for different segments

only FCEV versus BEV (one battery) and ICE Biodiesel



Lowest TCO for different segments

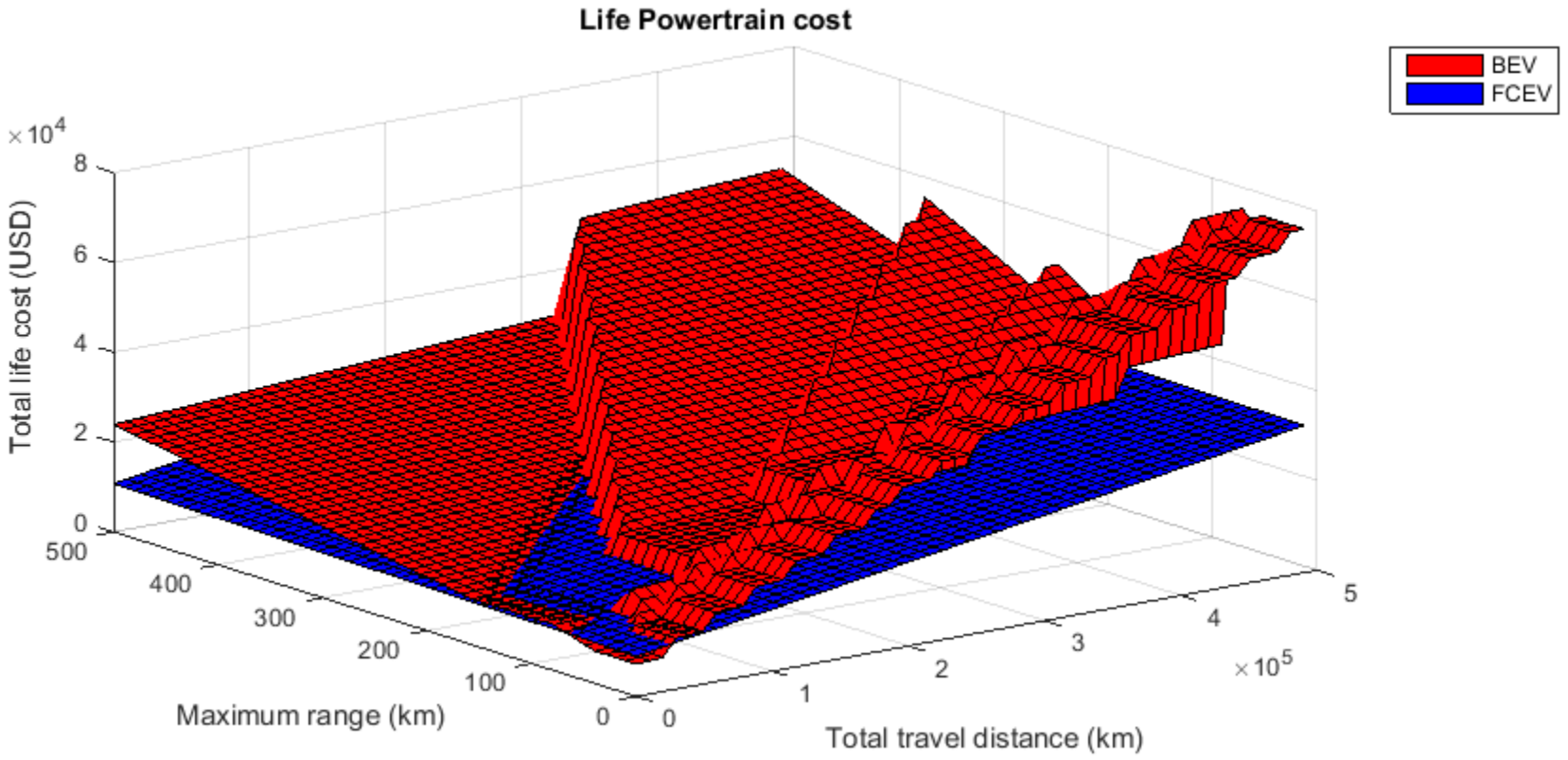
all investigated powertrains compared (BEV-one battery)



Note: REX niche is for cars with 67% electric drive and 33% REX

Lowest TCO for different segments

Battery utilization 667C (then battery replacement)



Cost of using battery to store energy

Assume battery price for cars 200 €/kWh

for end stop charged buses 400 €/kWh

Cost for storing 1 kWh in battery:

667 full cycles ⇒ 0.30 €/kWh

1800 full cycles ⇒ 0.11 €/kWh

13000 full cycles ⇒ 0.03 €/kWh

The cost of electricity itself ~0.10 € / kWh