Ponto de encontro
Lisboa E-Nova

LISBOA e·nova
AGÊNCIA DE ENERGIA E AMBIENTE DE LISBOA

Hidrogénio e mobilidade sustentável

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INSTITUTO DOM LUIZ

Hydrogen in the world?

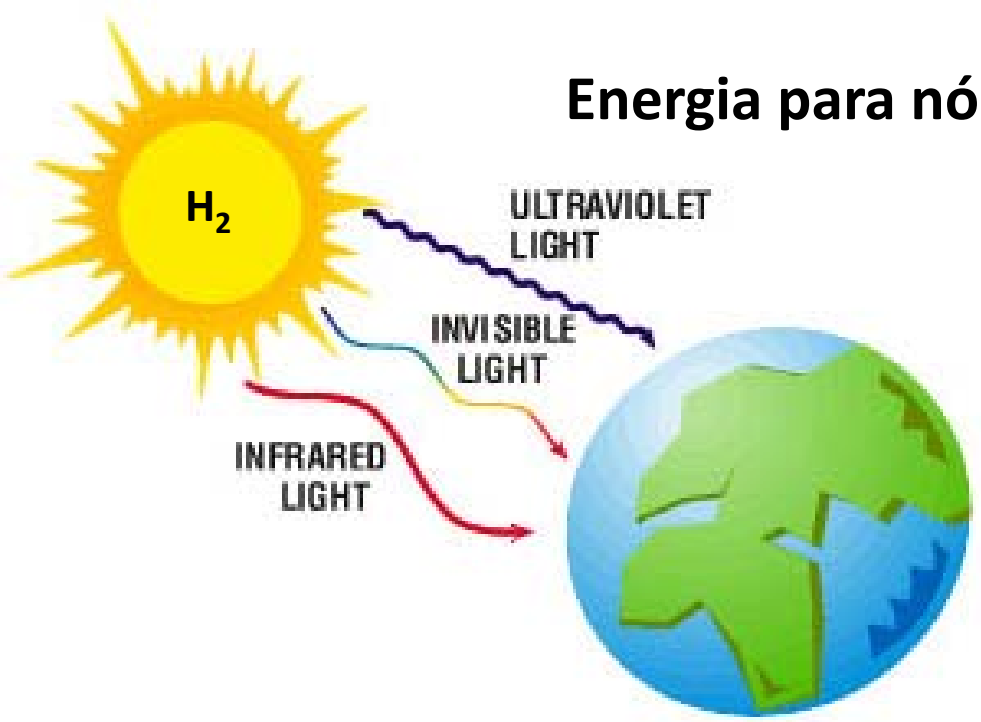
Temperature differences.....wind

Food & bioenergy

Solar Photovoltaic

Population grow....

Hidrogénio no mundo?

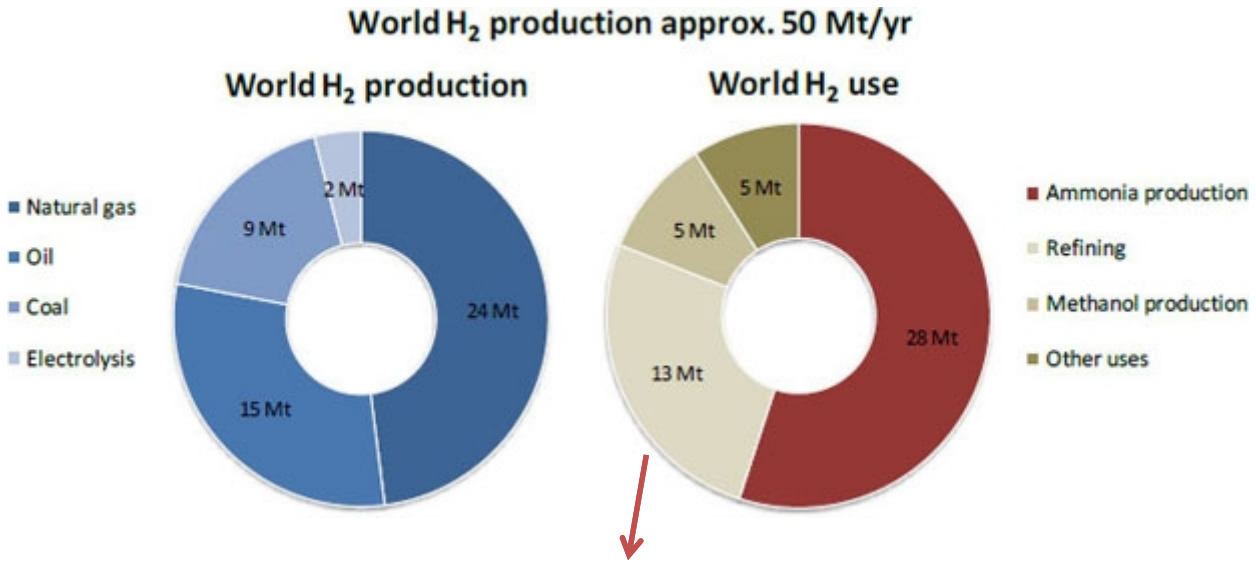


Energia para nós

Mas tamém H_2....

- **Fertilizantes (NH3)**
- **Indústria quimica**
- **Refinação petróleo**

Hidrogénio no mundo?



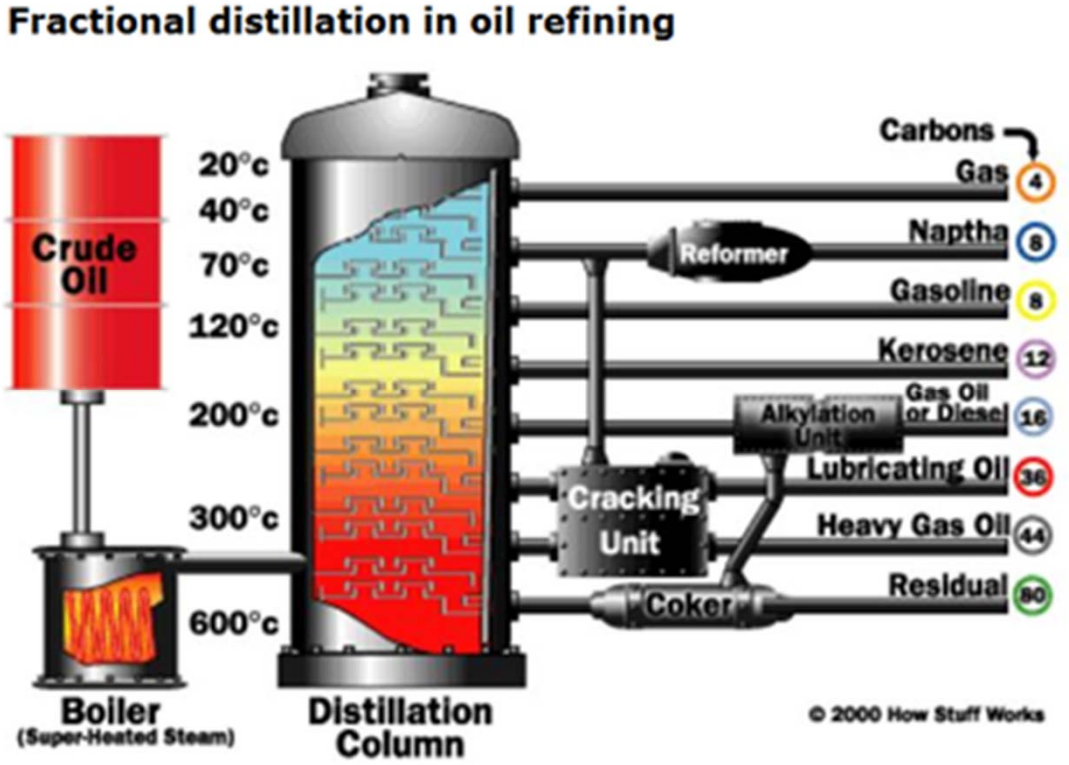
~ 26% Hydrocracking & Desulfurization

Reformação de gás natural

39 Mtoe to 1831 Mtoe of diesel & gasoline in transportation 2%.... (2012)

~ 1Mton H_2 production for transports in world

Refinação Portugal 2017



Gasoline 95 e 98
GPL

1.1 Mton

Diesel

4.5 Mton

et al....

~ 70 000 ton H_2
(1%)

galp energia

PORDATA
Base de Dados Portugal Contemporâneo

Hidrogénio no transporte ?

Porto and Sines refinery

~ 9-12 kg CO2eq/kg H_2

Emissions

Energy

Reformação gás natural

~ 180 MJ/kg H_2

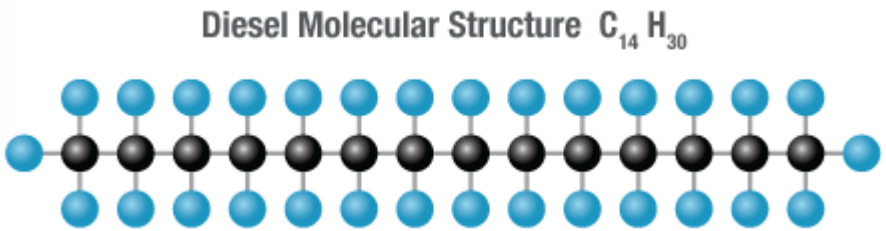
$$CH_4 + H_2O(1100^oC) \rightarrow CO + 3H_2 \quad (\Delta H=+206.16\ kJ/molCH4) \quad (1)$$

$$CO + H_2O \rightarrow CO_2 + H_2 \quad (\Delta H=-41.15\ kJ/molCO) \quad (2)$$

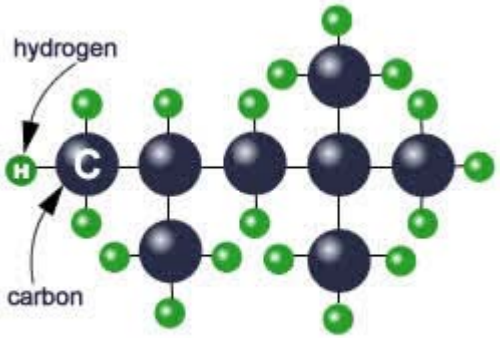
Source:

- Life cycle inventory analysis of hydrogen production by the steam-reforming process: comparison between vegetable oils and fossil fuels as feedstock;
- Hydrogen Production via Natural Gas Reforming Process – A Life Cycle Assessment Approach

Casa-Trabalho Portugal



C:H ~ 1:2
40 MJ/kg



65%

35%

e.g. Lisbon

90% motorized road (50% of trips by car/motorcycle 40% by bus)

ACEA European Automobile Manufacturers Association

eurostat

World Business Council for Sustainable Development

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UITP ADVANCING PUBLIC TRANSPORT

Exemplos de métricas Indicadores

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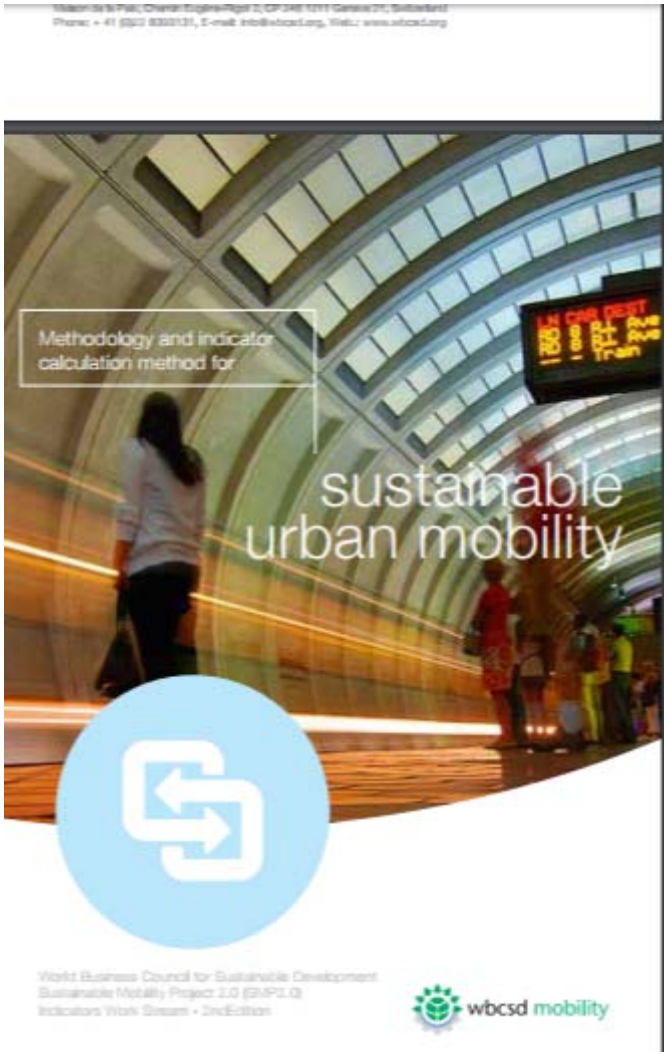
Mobilidade sustentável?



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Sustainable Mobility Project 2.0 (SMP2.0) Indicators Work Stream - 2nd Edition

http://wbcsdpublications.org/wp-content/uploads/2016/01/SMP2.0_Sustainable-Mobility-Indicators_2ndEdition.pdf

Mobilidade sustentável?

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Accessibility for mobility impaired groups	Accessibility for impaired	S	Q
Air polluting emissions	Air pollution	Q	
Noise hindrance	Noise hindrance	Q	
Fatalities	Fatalities	Q	
Access to mobility services	Access	Q	
Quality of public area	Public area	Q	
Urban Functional diversity	Functional diversity	Q	E
Commuting travel time	Travel time	Q	E
Economic Opportunity	Economic Opportunity	Q	E
Net public finance	Public Finance	E	
Mobility space usage	Space Usage	G	E
Emissions of greenhouse gases (GHG)	GHG	G	
Congestion and delays	Congestion	G	S
Energy efficiency	Energy efficiency	G	S
Opportunity for active mobility	Active mobility	G	S
Intermodal integration	Intermodal integration	S	
Comfort and pleasure	Comfort and pleasure	S	Q
Security	Security	S	Q

Table.1: Overview of the 19 Sustainable Urban Mobility Indicators indicating the dimensions of the sustainability of the mobility system. Source: Oran Consulting for WBCSD SMP2.0, 2014

Three dimensions refer to the sustainability of the resource use and/or the impacts of mobility in the city:

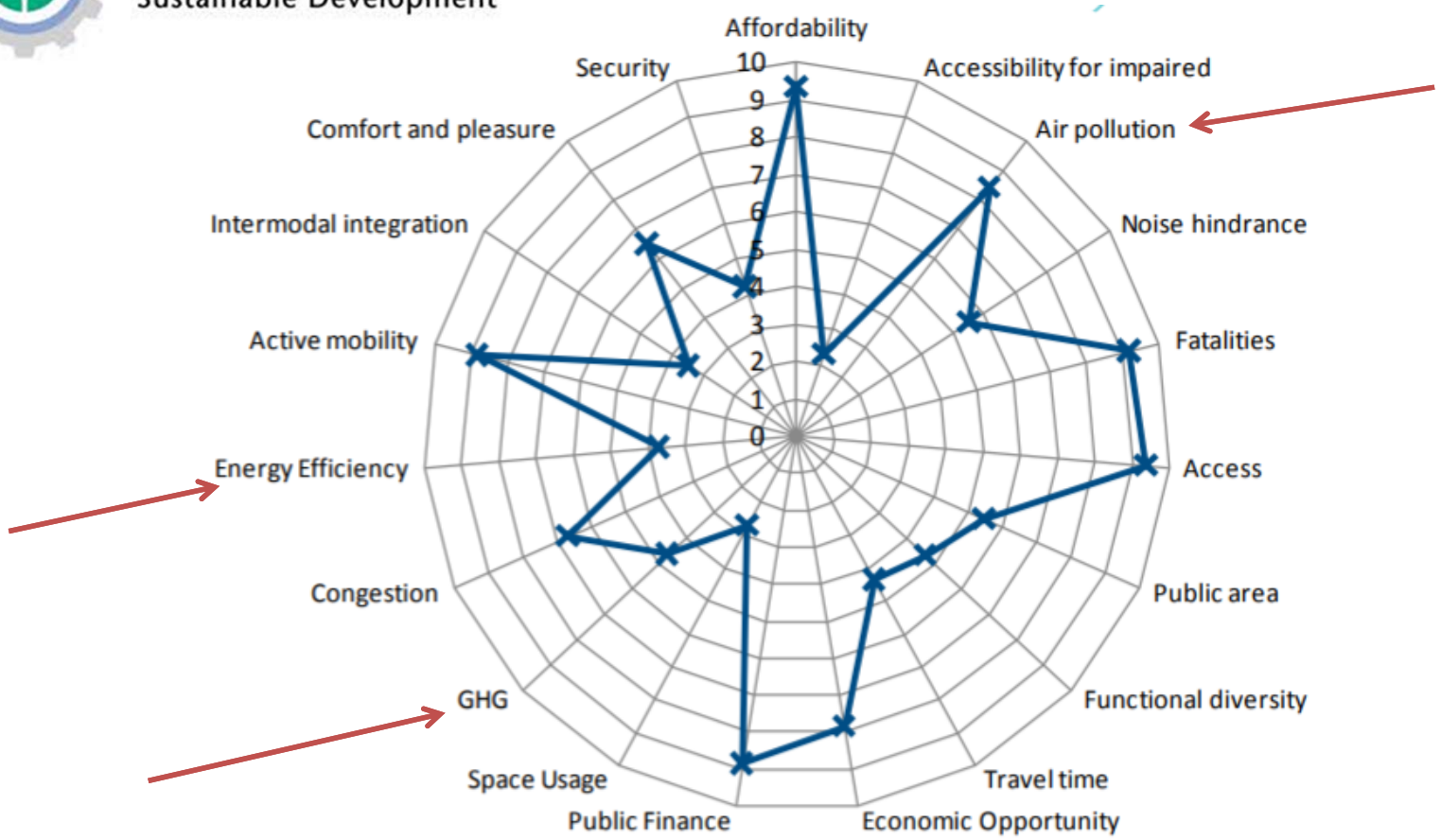
- G — Global environment
- Q — Quality of life
- E — Economic success
- S — Mobility system performance

4 dimensions- 19 Indicators

Mobilidade sustentável?

World Business Council for Sustainable Development

19 INDICATORS



Mobilidade sustentável?

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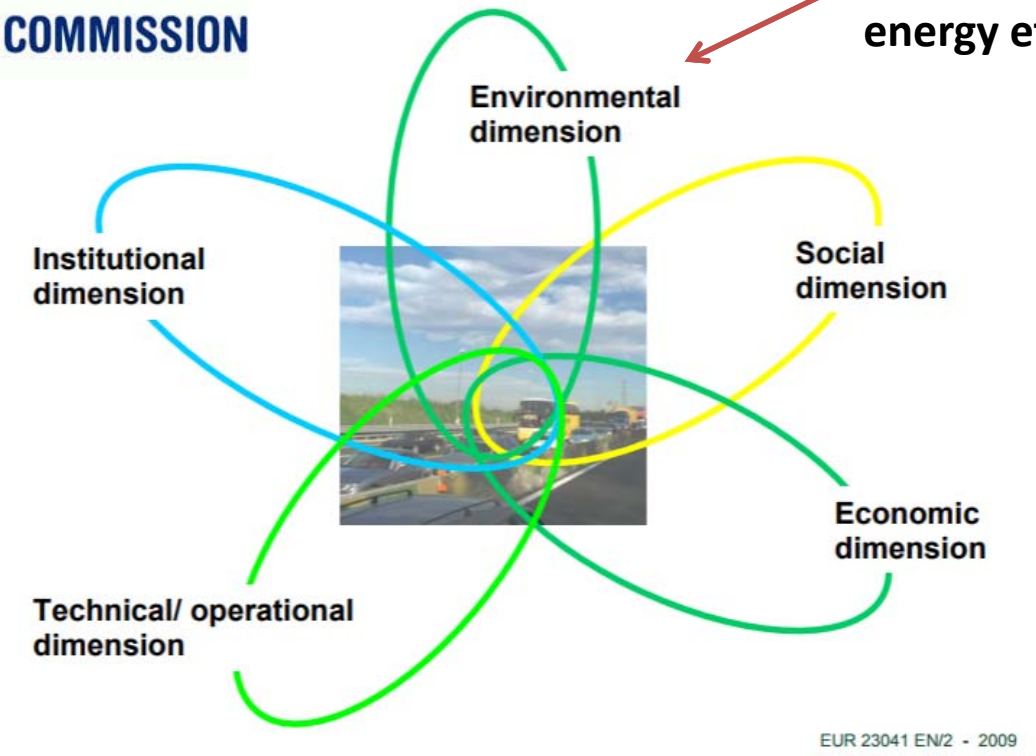
Transport emissions and energy efficiency



5 dimensions- 55 Indicators

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55 Indicators– Joint Research Centre

Table 1. Indicator Framework for the Evaluation of Transport Sustainability Performance

DIMENSION	THEME	RELATED INDICATORS
ECONOMIC	*Transport Demand and Intensity*	1.Volume of transport relative to GDP (tonne-km; passenger-km)
		2. Road transport (passenger and freight; tonne-km and passenger -km)
		3. Railway transport (passenger and freight; tonne-km and passenger-km)
		4. Maritime transport for goods and passengers (tonne-km and passenger-km)
		5. Inland waterway transport (passenger and freight; tonne-km and passenger-km)
		6. Air transport (passenger and freight; tonne-km and passenger-km)
		7. Intermodal transport (tonne-km and passenger-km)
	Transport Costs and Prices	8. Total per capita transport expenditures (vehicle parking, roads and transit services)
		9. Motor vehicle fuel prices and taxes (for gasoline and gas/ diesel)
		10. Direct user cost by mode (passenger transport)
		11. External costs of transport activities (congestion, emission costs, safety costs) by transport mode (freight and passenger)
		12. Internalization of costs (implementation of economic policy tools with a direct link with the marginal external costs of the use of different transport modes)
		13. Subsidies to transport
		14. Taxation of vehicles and vehicle use
		15. % of GDP contributed by transport
		16. Investment in transport infrastructure (per capita by mode/ as share of GDP)
	Infrastructure	17. Road quality - paved roads, fair/ good condition
		18. Total length of roads in km by mode

http://publications.jrc.ec.europa.eu/repository/bitstream/JRC54971/sust_transp_ind_report_final.pdf

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		19. Density of infrastructure (km-km^2)
SOCIAL	***Accessibility and Mobility***	20. Average passenger journey time
		21. Average passenger journey length per mode
		22. Quality of transport for disadvantaged people (disabled, low incomes, children)
		23. Personal mobility (daily or annual person-km and trips by income group)
		24. Volume of passengers
	Risk and Safety	25. Persons killed in traffic accidents (number of fatalities - 1000 vehicle km; per million inhabitants)
		26. Traffic accidents involving personal injury (number of injuries – 1000 vehicle km; per million inhabitants)
	Health Impacts	27. Population exposed to and annoyed by traffic noise, by noise category and by mode associated with health and other effects
		28. Cases of chronic respiratory diseases, cancer, headaches. Respiratory restricted activity days and premature deaths due to motor vehicle pollution
	Affordability	29. Private car ownership
		30. Affordability (portion of households income devoted to transport)
	Employment	31. Contribution of transport sector (by mode) to employment growth

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ENVIRONMENTAL	***Transport Emissions***	32. NOx emissions (per capita)
		33. VOCs emissions (per capita)
		34. PM_{10} and $PM_{2.5}$ emissions (per capita)
		35. SOx emissions (per capita)
		36. O_3 concentration (per capita)
		37. CO_2 emissions (per capita)
		38. N_20 emissions (per capita)
		39. CH_4 emissions (per capita)
	Energy Efficiency	40. Energy consumption by transport mode (tonne-oil equivalent per vehicle km)
		41. Fuel consumption (vehicles-km by mode)
	Impacts on Environmental Resources	42. Habitat and ecosystem disruption
		43. Land take by transport infrastructure mode
	Environmental Risks and Damages	44. Polluting accidents (land, air, water)
		45. Hazardous materials transported by mode
	Renewables	46. Use of renewable energy sources (numbers of alternative-fuelled vehicles) - use of biofuels
TECHNICAL and OPERATIONAL	***Occupancy of Transportation***	47. Occupancy rate of passenger vehicles
		48. Load factors for freight transport (LDV, HDV)
	Technology Status	49. Average age of vehicle fleet
		50. Size of vehicle fleet (vehicle/ 1 mln. inhabitants)
		51. Proportion of vehicle fleet meeting certain air emission standards (Euro IV, Euro V etc.)
INSTITUTIONAL	***Measures to Improve Transport Sustainability***	52. R&D expenditure on "eco vehicles" and clean transport fuels
		53. Total expenditure on pollution prevention and clean-up
		54. Measures taken to improve public transport
	Institutional Development	55. Uptake of strategic environmental assessment in the transport sector

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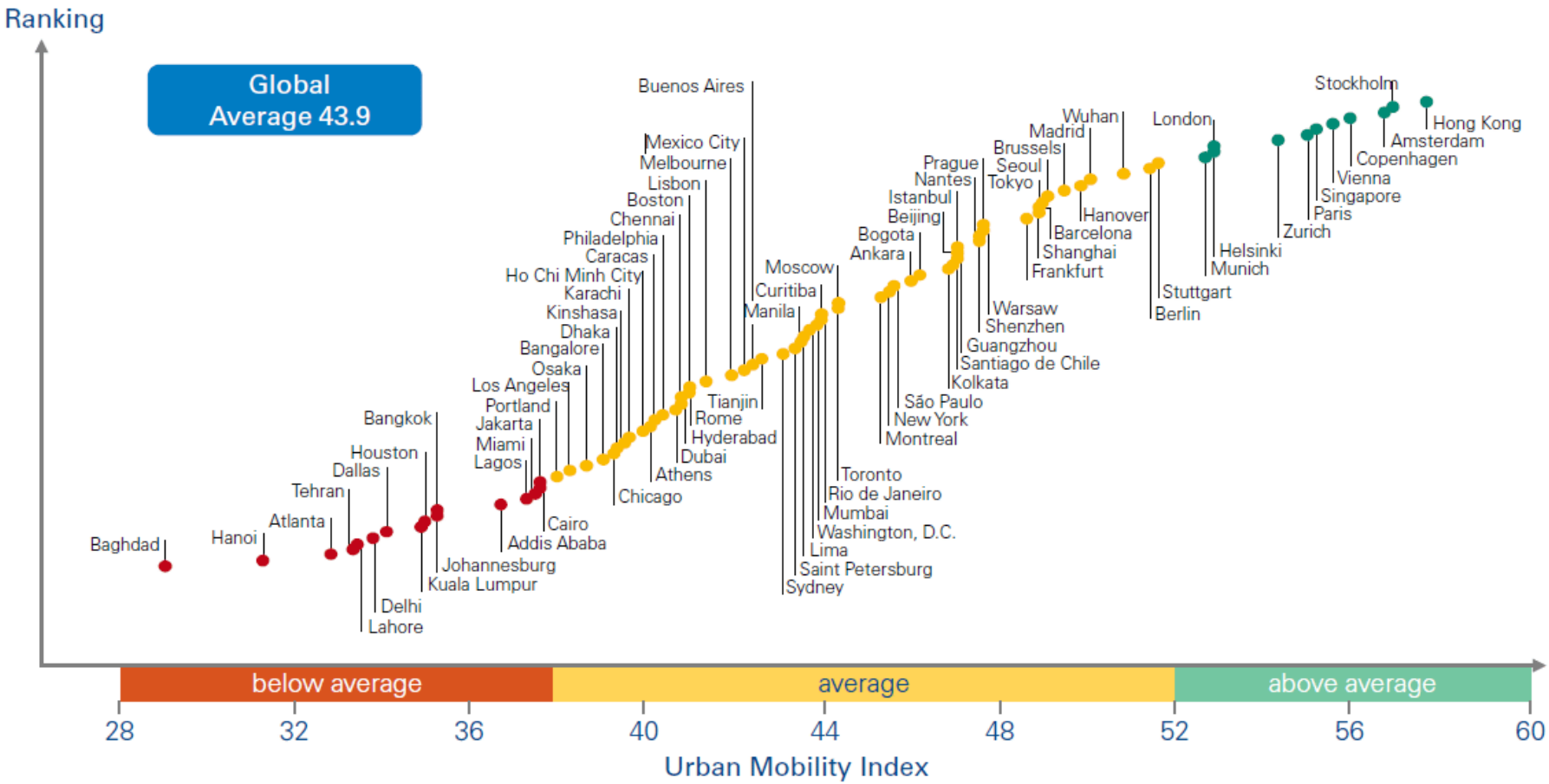
UITP ADVANCING PUBLIC TRANSPORT

International organisation for public transport

Figure 6: Arthur D. Little' Urban Mobility Index 2.0

19 INDICATORS



Source: Arthur D. Little Urban Mobility Index 2.0; UITP is independent of this index, which does not necessarily reflect its opinion; 100 index points for city that would achieve best performance on each criteria.

Figure 8: Top 11 cities with above average mobility score

	Fin. attract. of PT (cost of 5 km PT/ cost of 5 km car)	Share of public transport in modal split [%]	Share of zero-emission modes in modal split [%]	Roads density (deviation from optimum) [km/km^2]	Cycle path network density [km/ths km^2]	Urban agglomeration density [citizens/km^2]	Smart card penetration [cards/capita]	Bike sharing performance [shared bikes/ million citizens]	Car sharing performance [shared cars/million citizens]	Density of vehicles registered [vehicles/capita]	Frequency of the busiest public transport line [times/ day]	Initiatives of public sector (0 to 10 scale)	Transport related CO_2 emissions [kg/capita]	Annual average NO_2 concentration [mcg/m^3]	Annual average PM_{10} concentration [mcg/m^3]	Traffic related fatalities per 1 million citizens	Dynamics of share public transport in modal split [%]	Dynamics zero-emission modes in modal split [%]	Mean travel time to work [minutes]	OVERALL SCORE
Maturity indicators													Performance indicators							
1 Hong Kong	1.7	55%	38%	2.0	187	6.5	3.1	0	0	0.07	324	10	776	50.0	50.0	16.2	+20%	0%	36.6	58.2
2 Stockholm	6.7	33%	34%	0.5	4,041	3.7	0.6	852	400	0.40	212	10	1,348	12.5	16.7	9.4	-7%	+89%	33.7	57.4
3 Amsterdam	3.0	8%	50%	1.7	3,502	3.2	0.7	527	1,219	0.32	130	10	844	30.0	24.7	19.5	+12%	+13%	35.5	57.2
4 Copenhagen	4.8	27%	33%	2.7	3,977	2.7	0.1	1,025	246	0.24	238	10	812	56.0	28.0	4.1	+123%	-15%	29.7	56.4
5 Vienna	3.9	39%	34%	0.6	2,948	3.8	0.0	692	415	0.39	277	10	1,111	21.7	21.5	16.1	+15%	+13%	29.3	56.0
6 Singapore	2.6	48%	23%	2.6	280	7.3	2.9	19	57	0.18	233	9	1,381	22.0	29.0	32.5	+17%	+64%	36.8	55.6
7 Paris	2.9	34%	50%	8.8	3,520	3.8	0.6	2,224	219	0.46	267	10	1,163	39.2	38.0	23.9	+7%	0%	38.6	55.4
8 Zurich	3.8	39%	31%	0.7	3,700	4.2	0.0	232	1,064	0.54	149	10	1,200	30.1	19.1	15.4	+15%	+3%	30.4	54.7
9 London	3.9	34%	26%	10.8	254	5.6	3.1	1,012	253	0.39	468	10	1,050	37.0	22.9	26.6	+10%	+4%	44.1	53.2
9 Helsinki	3.6	27%	40%	2.1	4,678	2.3	0.9	0	70	0.48	246	10	1,228	28.0	20.2	13.9	-16%	+8%	28.5	53.2
11 Munich	4.6	21%	42%	0.1	3,862	3.0	0.0	727	640	0.56	210	10	1,351	35.3	21.7	15.3	0%	+11%	30.1	53.0

Source: Arthur D. Little Urban Mobility Index 2.0

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Exemplos de métricas Indicadores

- **Eficiência energética (menos MJ/pkm)**
- **Sem emissões escape**
- **Menos CO2eq**

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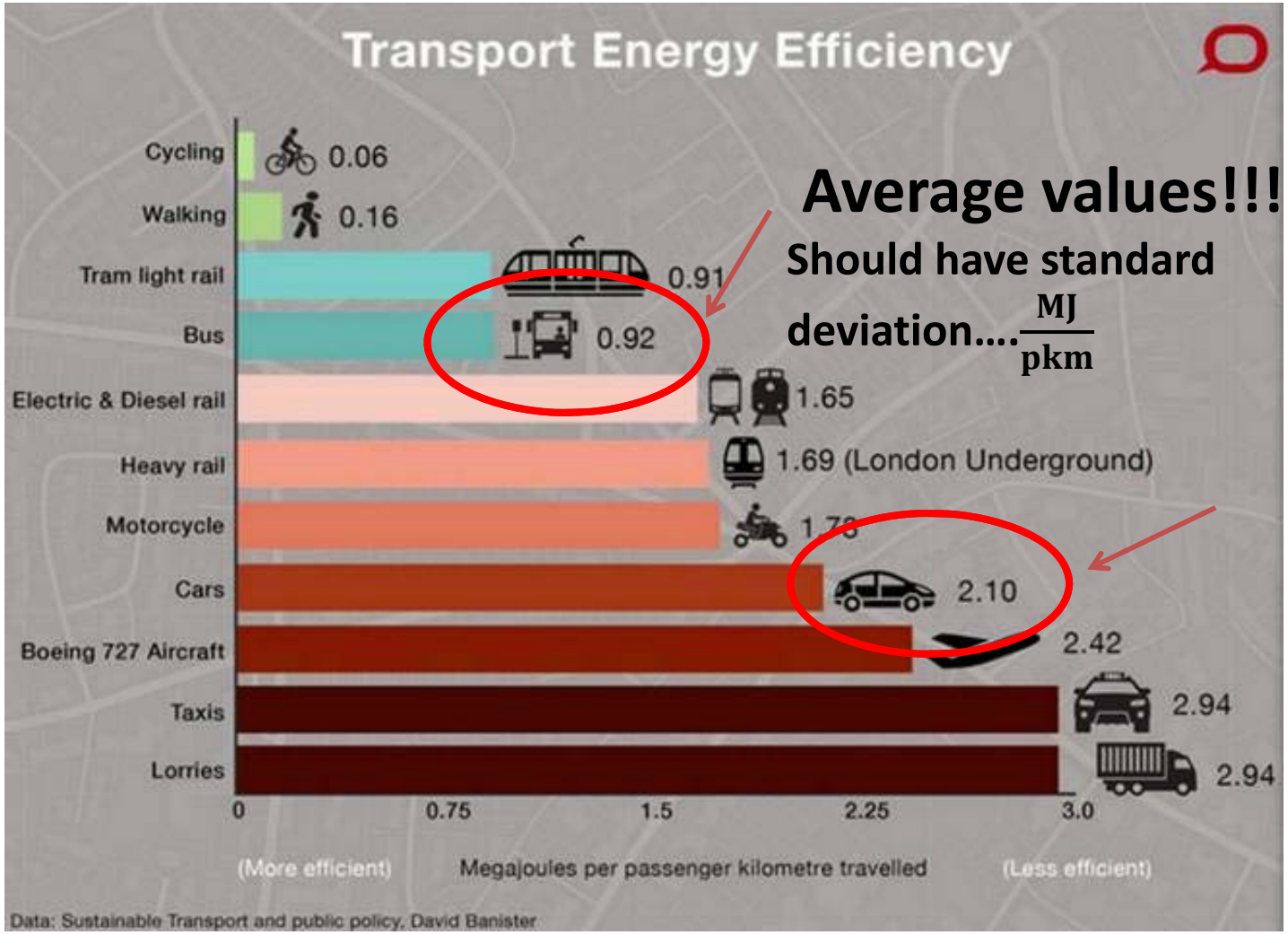
Eficiência energética?



Eficiência energética?

100% elétrico com geração *off-board*

150 Wh/km
0.54 MJ/km

~1500 kg
250 km

~ 1 pessoa

0.8 Lgasoline eq/km
0.26 MJ/km

~1800 kg
625 km

100% elétrico mas com geração de eletricidade *on-board* por H_2 e fuel cell

Eficiência energética?

250 kWh/200 km
4.5 MJ/km
0.12 MJ/pkm

~ 35 em 70 pessoas

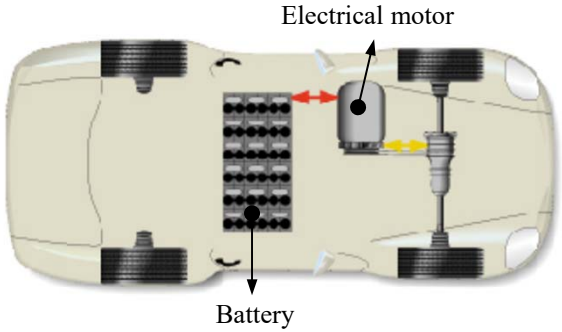
100% elétrico com geração *off-board*

3 L/km (12 kg/100km)
14 MJ/km @70 bar
0.4 MJ/pkm
2*114 kW FC

100% elétrico mas com geração de eletricidade *on-board* por H_2 e fuel cell

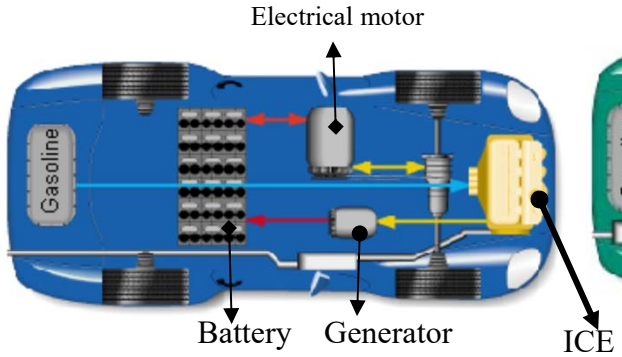
Sistemas propulsão?

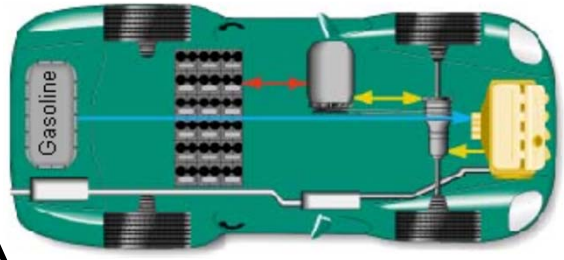
Plug-In

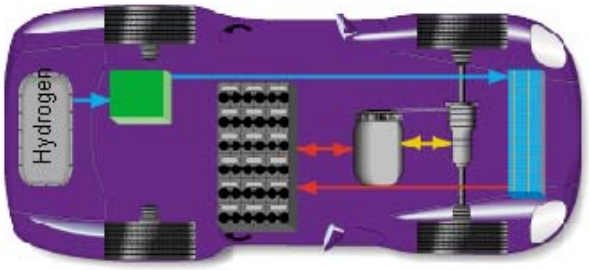


Pure electric (efic. 60-70%)

Hybrids (efic. 20-30%)



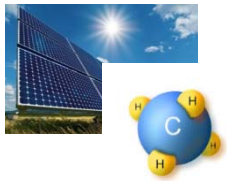




Fuel cell (efic. 40-50%)

Energy sources and powertrains?

Refinery (distillation column)



Power plants (vapour cycle) renewables

Reforming

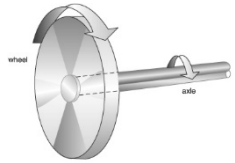
Transesterification

Fermentation

Flexibility…..

Fuel/technology	BEV	PHEV	HEV	ICEV
Electricity	✓	✓		
Hydrogen		✓	✓	✓
Gasoline		✓	✓	✓
Diesel		✓	✓	✓
Biodiesel		✓	✓	✓
Ethanol		✓	✓	✓

Efficiency…..

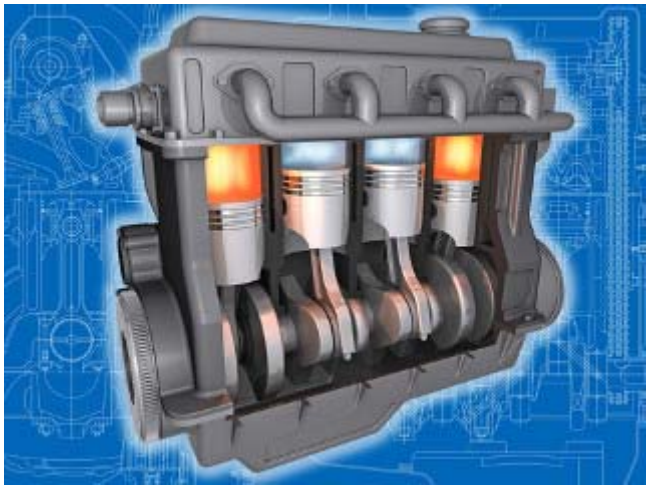


Primary energy

Final energy

Useful energy

Qualidade do ar?



Minimizar combustão interna

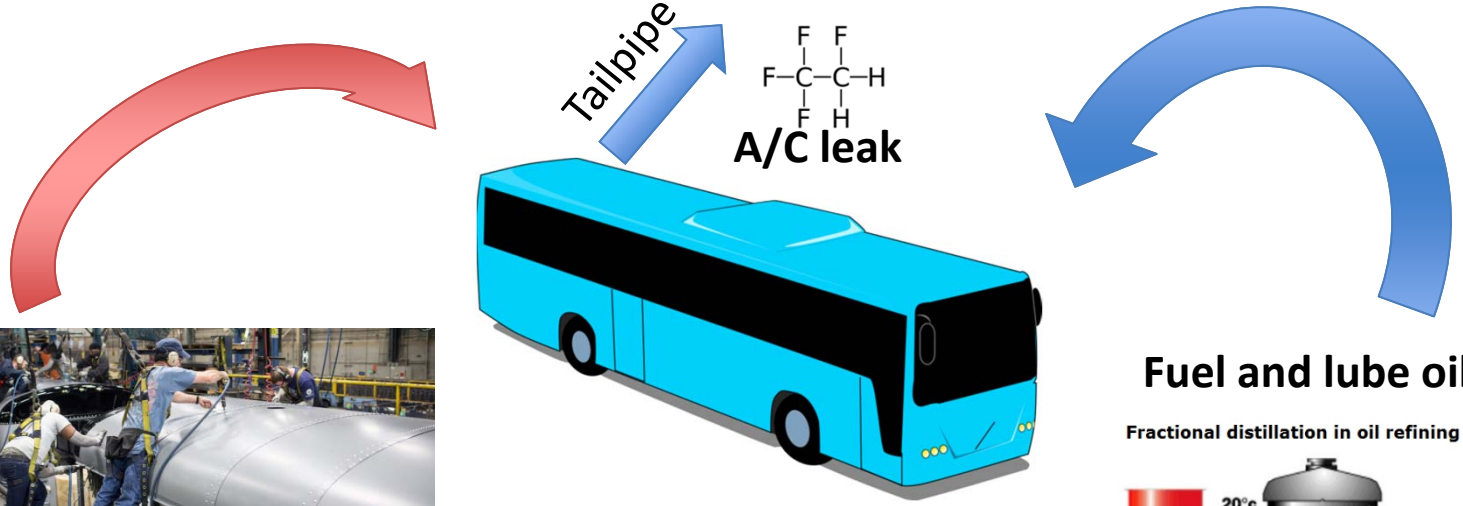
Ou

Eliminar!

Eletric *off-board* versus eletric *on-board* H_2

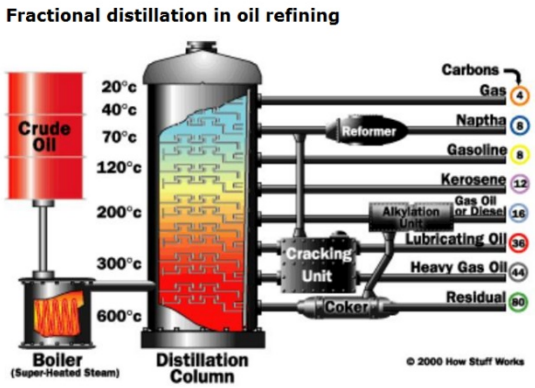
Comparar Global GHG emissions?

WTW Well-to-Wheels



Manufacturing

Fuel and lube oil production



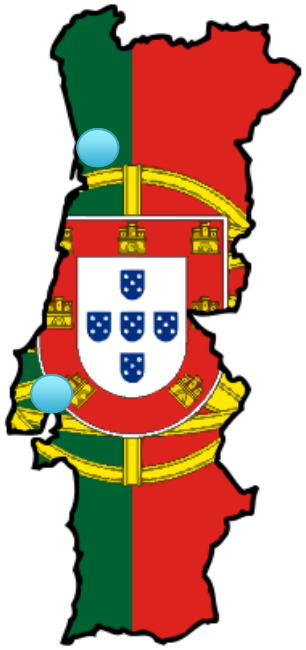
CTG Cradle-to-Grave

Comparação sistemas?

renewables

Refinery (distillation column)

Fuel/technology	BEV	HEV	ICEV
Electricity	✓		
Hydrogen		✓	
Diesel (40 L/100km)			✓



~ 50 000 km/bus.year

473 STCP Porto+ 597 Carris = # **1070**

4.5 MJ/km*50000 km/year*1070 = $241*10^6$ MJ/year
($67*10^6$ kWh/year eletricidade)

14 MJ/km*50000 km/year*1070 = $749*10^6$ MJ/year
(6 420 ton H_2/year hidrogénio @70 bar)

Comparação sistemas?

renewables

Refinery (distillation column)

Fuel/technology	BEV	HEV	ICEV
Electricity	✓		
Hydrogen		✓	
Diesel			✓

η_{WTT} = 83%; η_{WTW}= **17%;** 15.4 gCO2eq/MJ + 70 gCO2eq/MJ

1.2* 764 *10^6 MJ/year — 764 *10^6 MJ/year

η_{WTT} = 89%; η_{WTW}= **63%;** 0 gCO2eq/MJ

1.12* 241*10^6 MJ/year — 241*10^6 MJ/year

η_{WTT} = 53%; η_{WTW}= **27%;** 13 gCO2eq/MJ

1.87*749*10^6 MJ/year — 749*10^6 MJ/year

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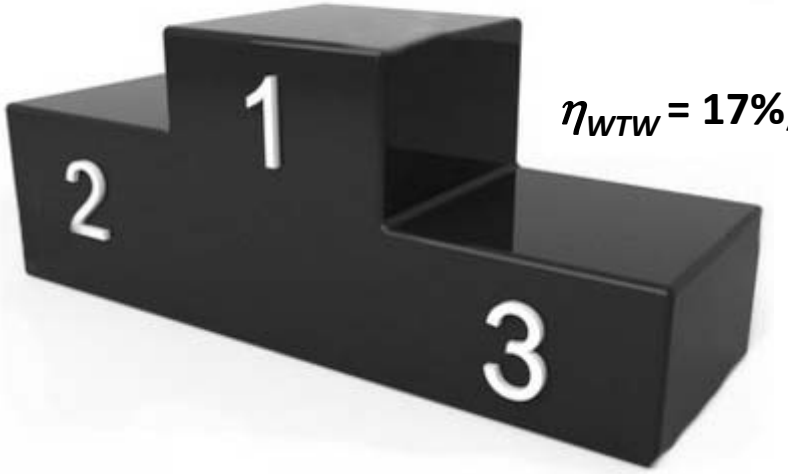
Primary energy — **Final energy**

Comparação sistemas?

η_{WTW}= 63%;

η_{WTW}= 27%;



η_{WTW} = 17%;

Eficiência energética de conversão energia primária em útil

Comparação sistemas?

0 gCO2eq/ano -100%;

9737 ton CO2eq/ano -85%;

65 244 tonCO2eq/ano ref;

Emissões CO2eq produção e uso combustível

Comparação sistemas?

Construção autocarros/ tempo de vida **~ 700 000 km**
1 substituição bateria e 1 fuel cell

0 gCO2eq/ano - 99 %;

+0.15 gCO_2/km

9737 ton CO2eq/ano - 85%;

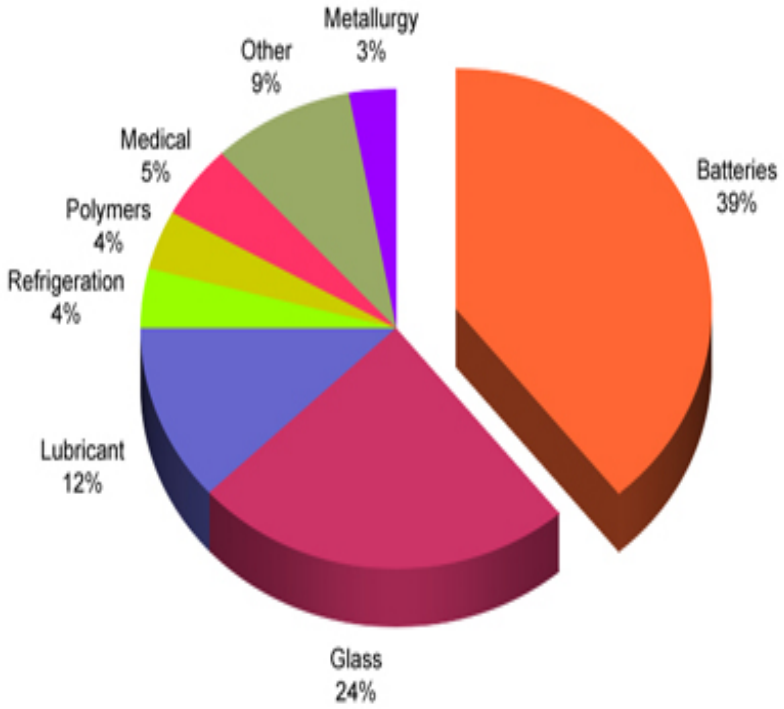
+0.1 gCO_2/km

65 244 tonCO2eq/ano ref;

+0.05 gCO_2/km

Materiais raros….

15566000 Ton world

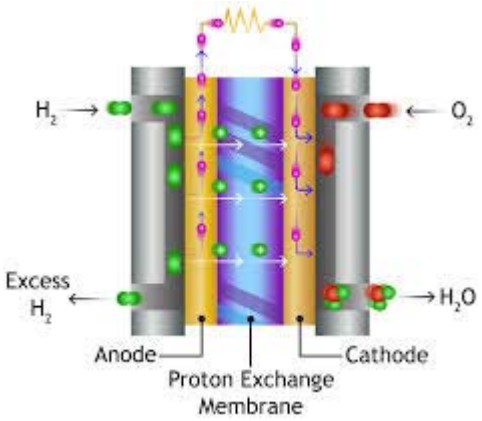


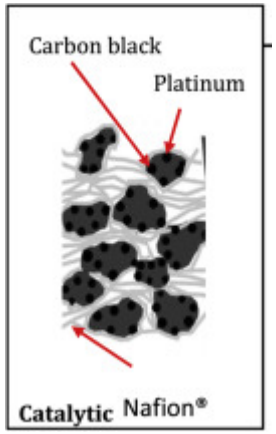
0.03 kg/kWh

Figure 1: Lithium consumption (2015).
http://batteryuniversity.com/learn/article/availability_of_lithium

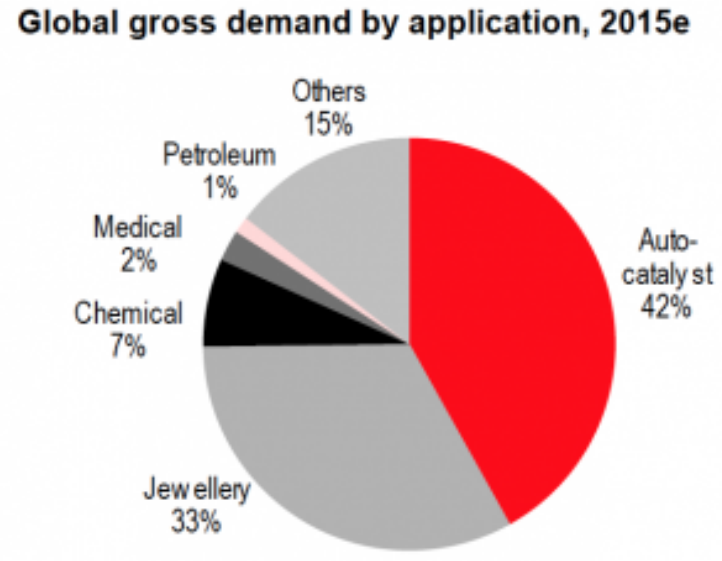
BEV – higher capacity battery ⇒ more kg of Li

Materiais raros….





69310 ton world



0.125 g/kW

Nafion/SnO2 nanocomposite membrane

FCHEV – PEM Fuel cell ⇒ nafion synthetic polymers (membrane) and platinum (electrodes)

Carla Silva camsilva@fc.ul.pt

Materiais raros?

1 substituição bateria e 1 fuel cell

ref; 0 Ton Li
0 ton Pt

2*1070*228kW*0.125 g/kW
= 0.06 Ton Pt

+

2*1070*40kWh*0.03 kg/kWh
= 2.6 Ton Li

2*1070*250kWh*0.03 kg/kWh
= 16 Ton Li

Hidrogénio?

Arpão e Tridente #2

Fuel cell

Submarinos …. Grande autonomia até 15 dias debaixo de água

Armazenamento hidretos metálicos aluminio

Hidrogénio?

~ Combustão ~200 **ton H_2/launch futuro fuel cell**

Viagens espaciais!!

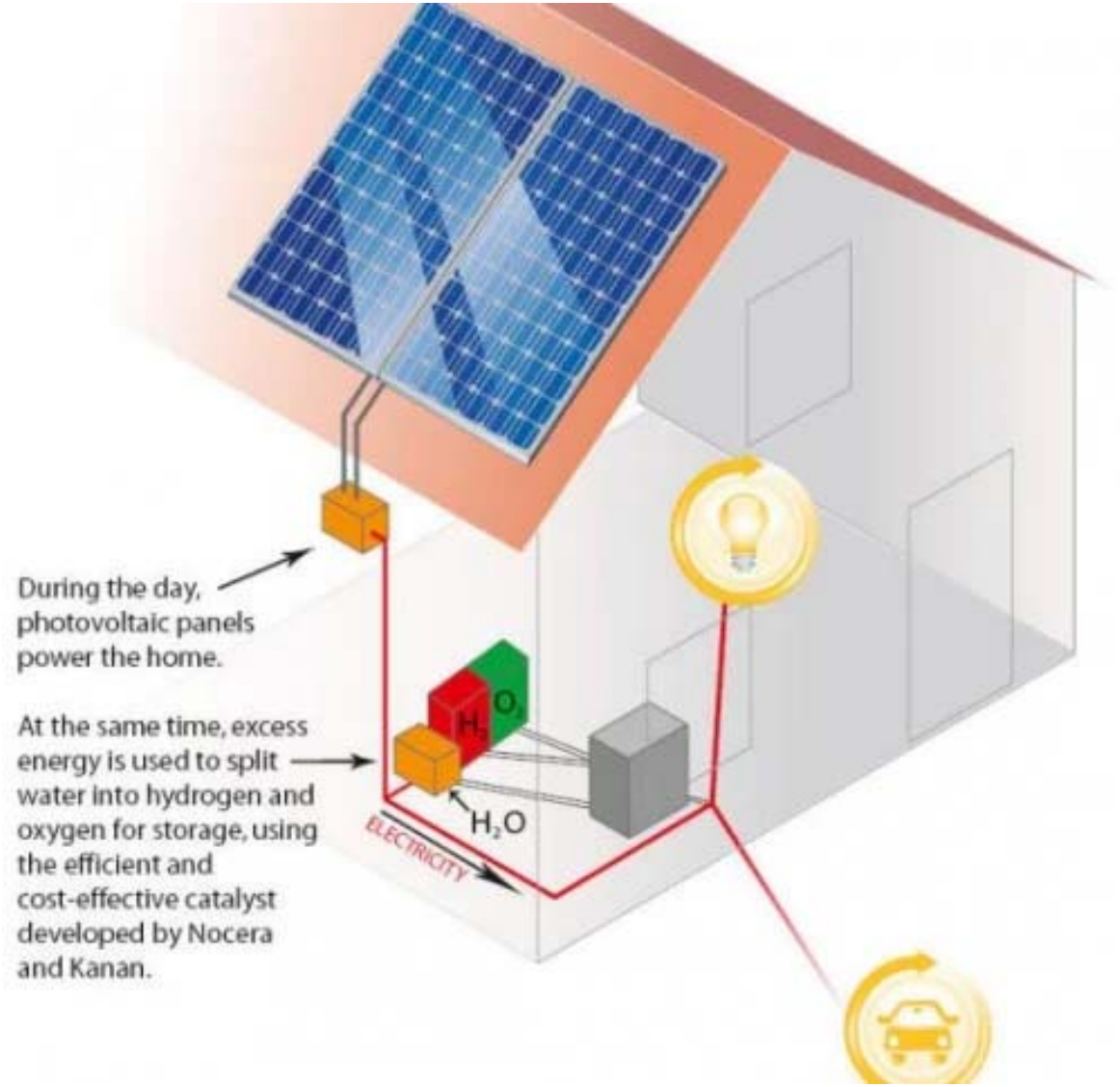
Each shuttle burns
1 892 705.9 litres
Loose extra 50%

-253ºC
0.07 kg/L

Hydrogen in the world?

Sora (ciclo da água em japonês)
Tóquio 2020

Hydrogen system?



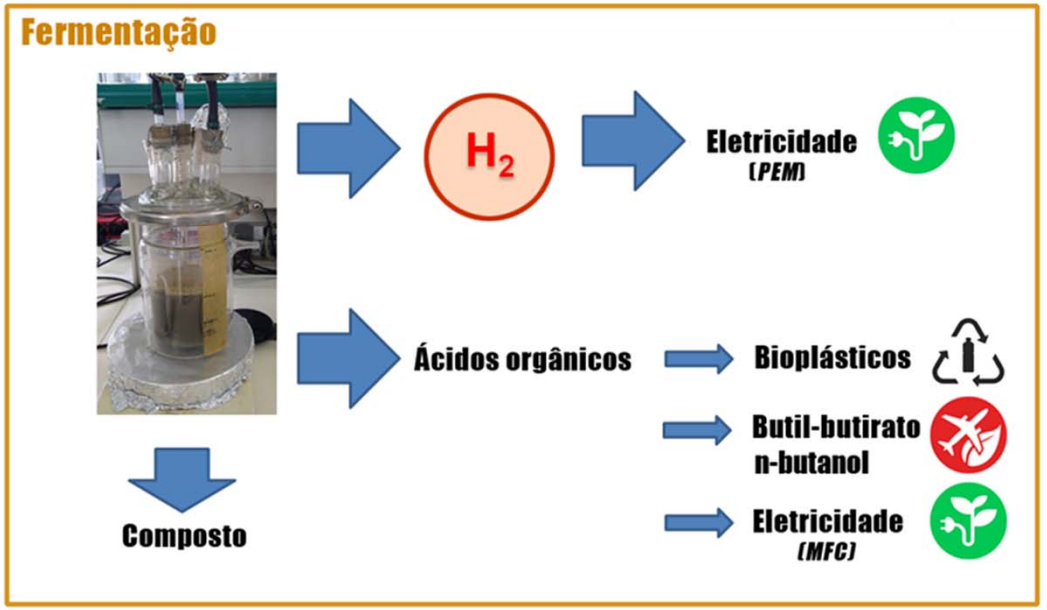
Massachusetts Institute of Technology

H_2 de lixo?

Biorefinaria

Desperdício Alimentar

Acondicionamento Doméstico



- Programa doutoral em **Engenharia do Ambiente**
- Bolsa de doutoramento **FCT: SFRH/BD/107780/2015**
- Entrega prevista *Janeiro de 2020*


1 031 000
toneladas de desperdício alimentar produzidos ao nível nacional
97 kg per capita

1 031 000 toneladas de desperdício alimentar

4 040 toneladas H_2

77 000 toneladas **ácidos**

788 000 toneladas **composto**

Sistemas sustentáveis e resilientes!!!!!

Com ou sem H_2....

Bem, no minimo com H_2 do Sol.....!!!

Ponto de encontro
Lisboa E-Nova

LISBOA e·nova
AGÊNCIA DE ENERGIA E AMBIENTE DE LISBOA

Hidrogénio e mobilidade sustentável

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