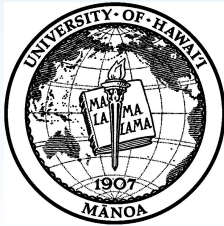


Transportation Sustainability Analysis: Alternative Fuel Vehicles



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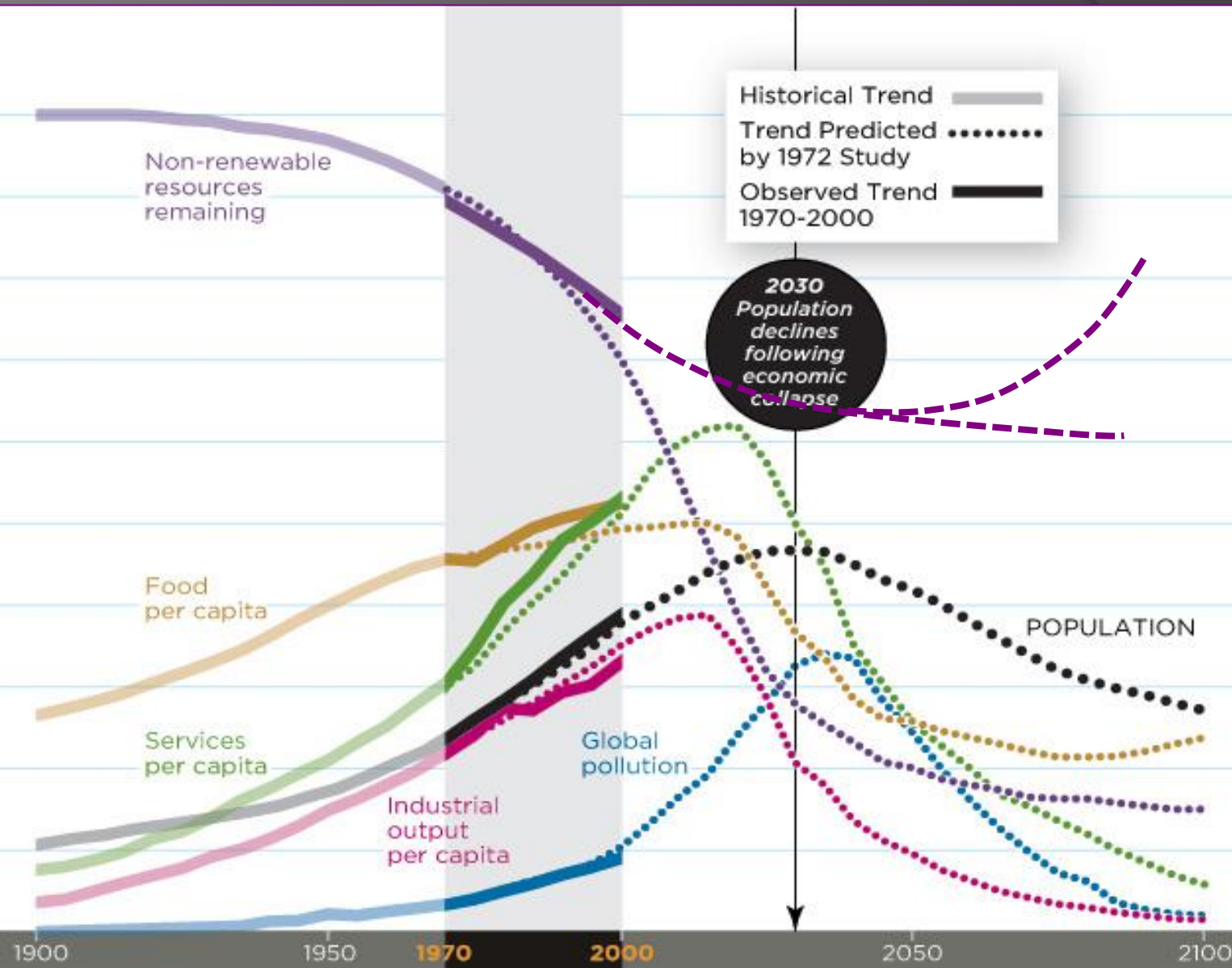
Outline

- i. Crisis
- ii. Sustainability
- iii. Framework
- iv. Analysis
- v. Results
- vi. Conclusion

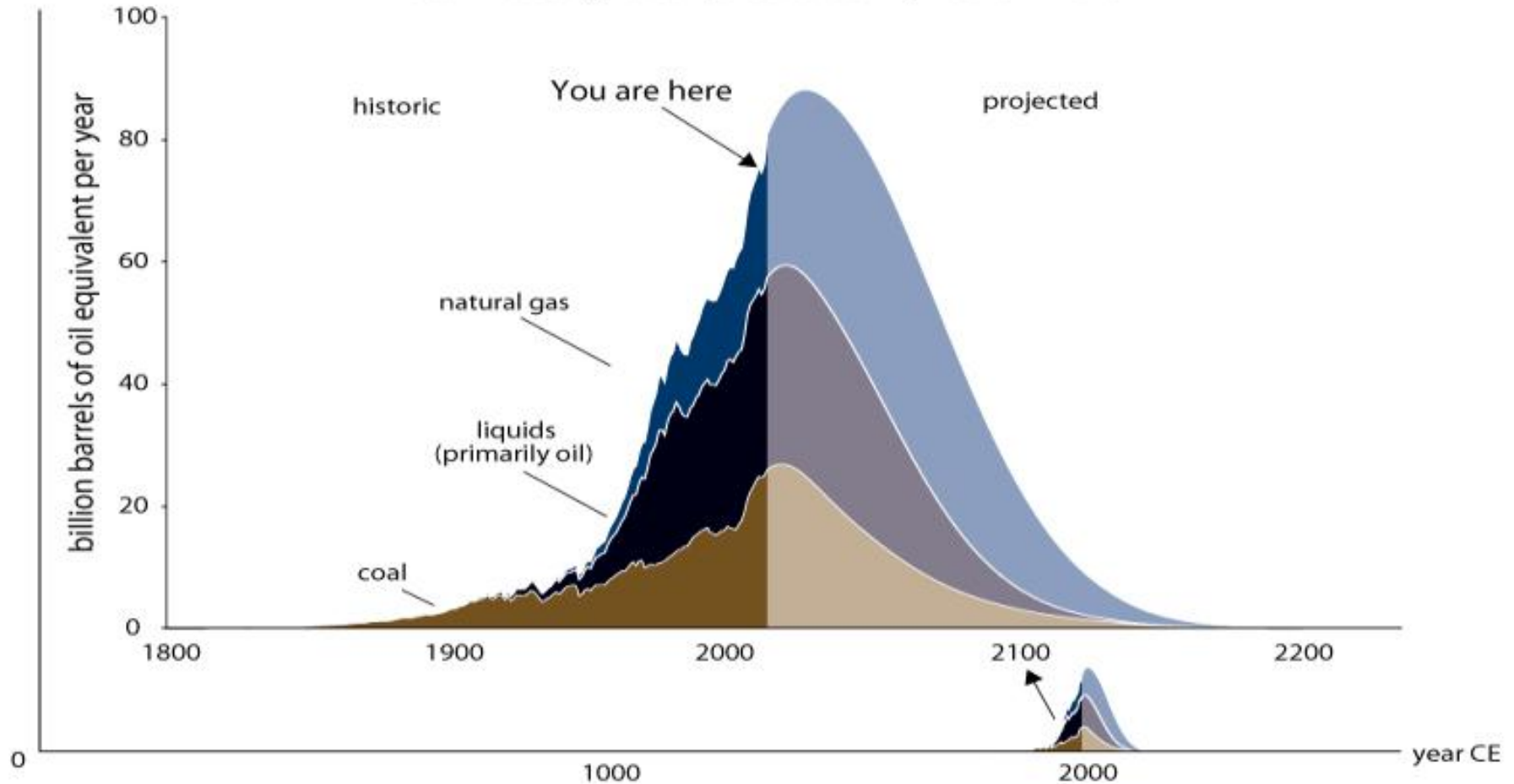


❖ In 1972, a team of experts from MIT presented a groundbreaking report called *The Limits to Growth*

❖ In 2012 Australian physicist G. Turner updated it with data from 1970 to 2000

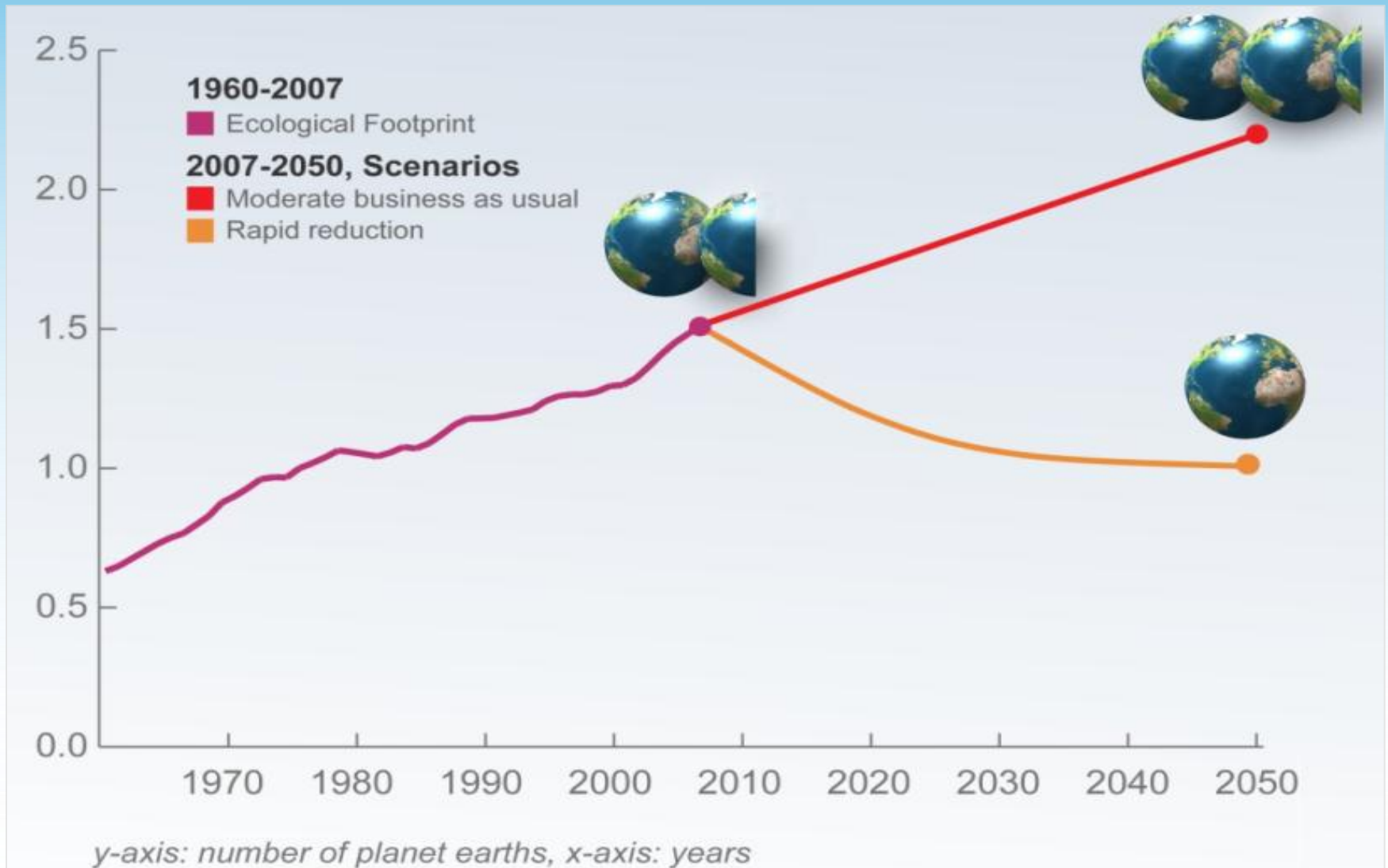


Fossil fuels: global production, 1800–2200

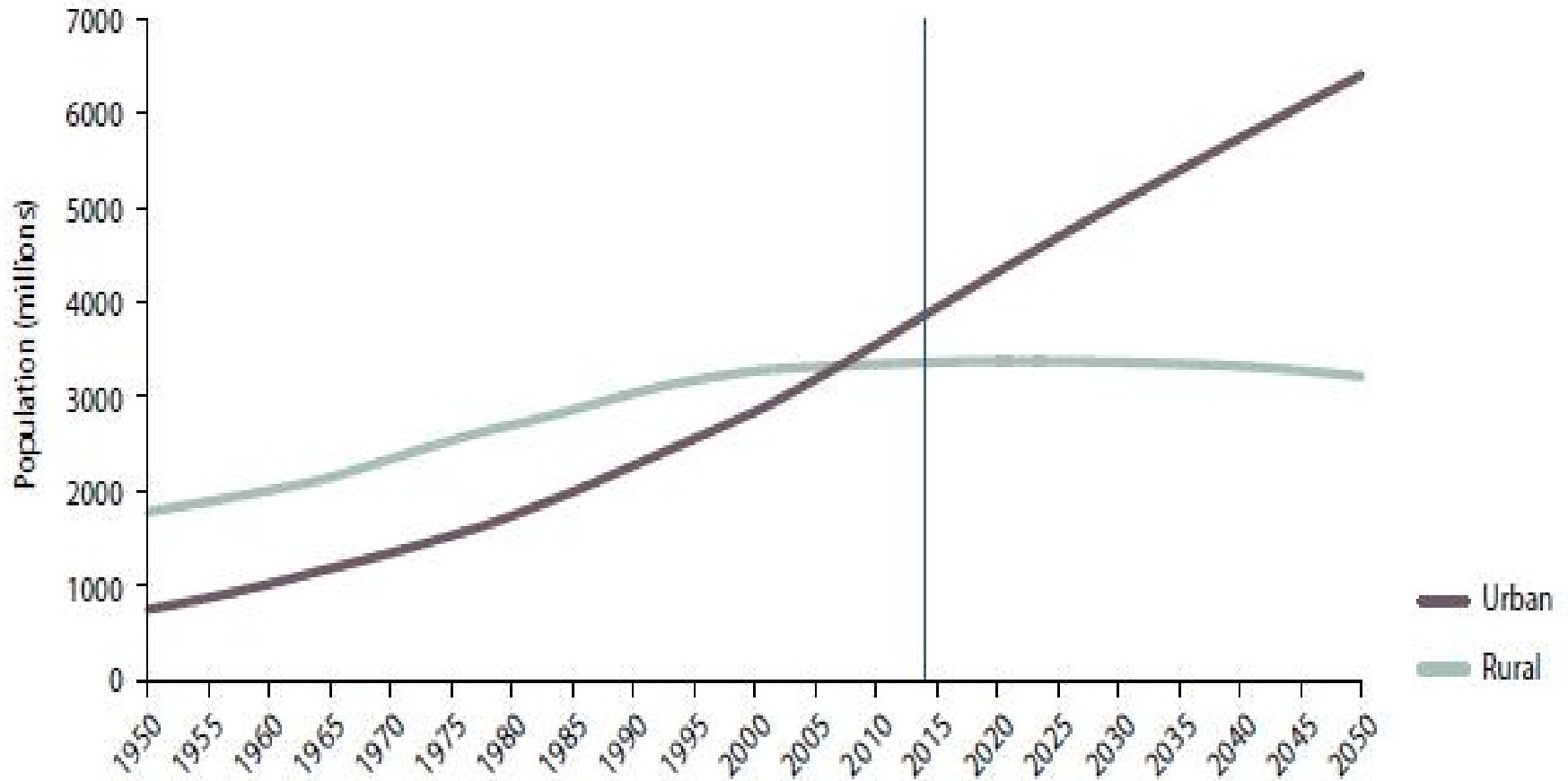


Rocky Mountain Institute © 2011. Published by Chelsea Green in *Reinventing Fire*. For more information see www.RMI.org/ReinventingFire.





United Nations Department of Economic and Social Affairs World Urbanization Prospects - The 2014 Revision

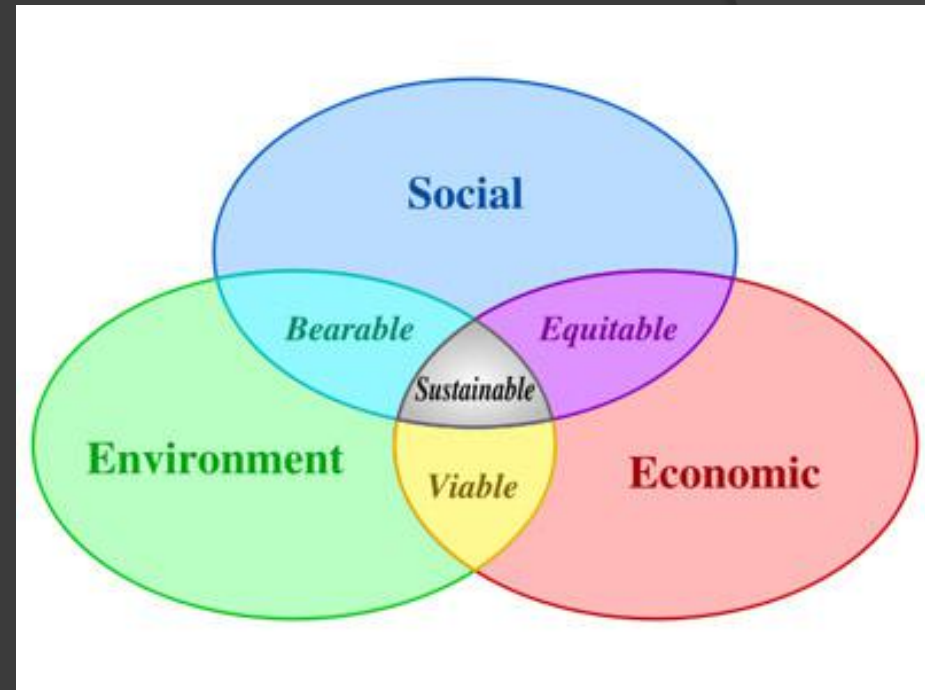




- i. Crisis
- ii. Sustainability
- iii. Framework
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- vi. Conclusion

Sustainability

- Sustainability can be applied to any system, to describe the maintenance of a balance within the system
- Integrates Environment, Economy, Energy, Society
- World Commission on Environment and Development (WCED):
Sustainability is a rate of development that meets the needs of the present without compromising the ability of future generations to meet their own needs



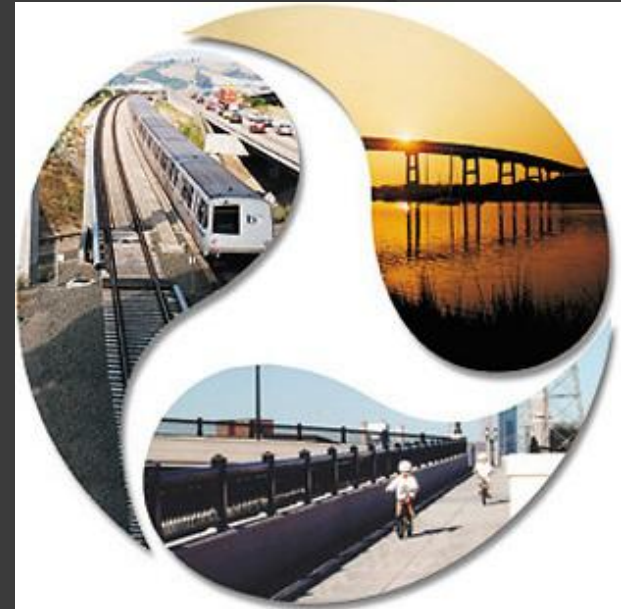
Sustainability ... How?

Transportation impacts on:

- ⦿ Environment
- ⦿ Society
- ⦿ Economy



**Incorporation
of
sustainability
into
transportation
planning**



1. Transportation system sustainability definition
2. Standard method for assessing transportation systems



Bits and Pieces Are Available



ENVISION™

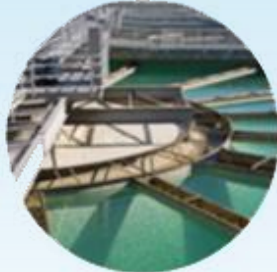


What Types of Infrastructure Does Envision Rate?



ENERGY

Geothermal
Hydroelectric
Nuclear
Coal
Natural Gas
Oil/Refinery
Wind
Solar
Biomass



WATER

Potable water distribution
Capture/Storage
Water Reuse
Storm Water Management
Flood Control



WASTE

Solid waste
Recycling
Hazardous Waste
Collection & Transfer



TRANSPORT

Airports
Roads
Highways
Bikes
Pedestrians
Railways
Public Transit
Ports
Waterways



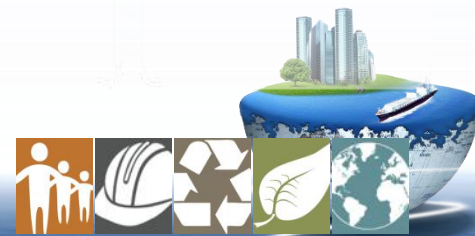
LANDSCAPE

Public Realm
Parks
Ecosystem Services
Natural Infrastructure



INFORMATION

Telecom
Internet
Phones
Satellites
Data Centers
Sensors



60 Credits in 5 Categories



QUALITY OF LIFE

Purpose, Community, Wellbeing



LEADERSHIP

Collaboration, Management, Planning



RESOURCE ALLOCATION

Materials, Energy, Water



NATURAL WORLD

Siting, Land and Water, Biodiversity



CLIMATE AND RISK

Emission, Resilience



Award Levels

Minimum Percentage of Points Achieved:

20%



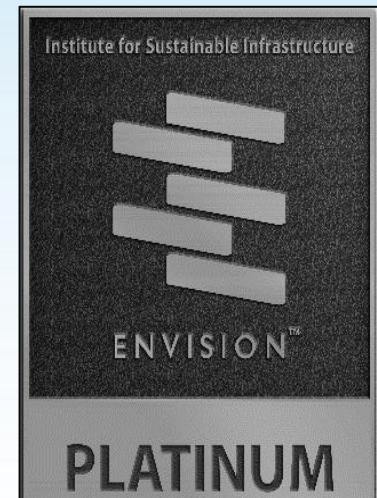
30%



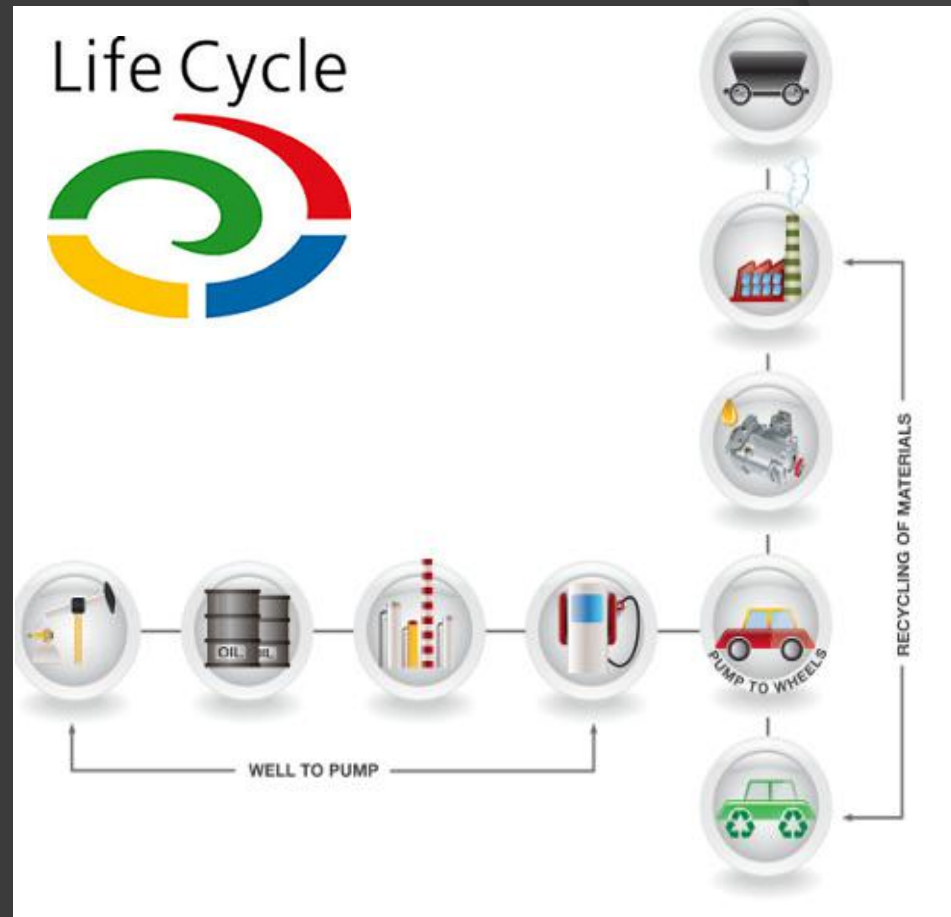
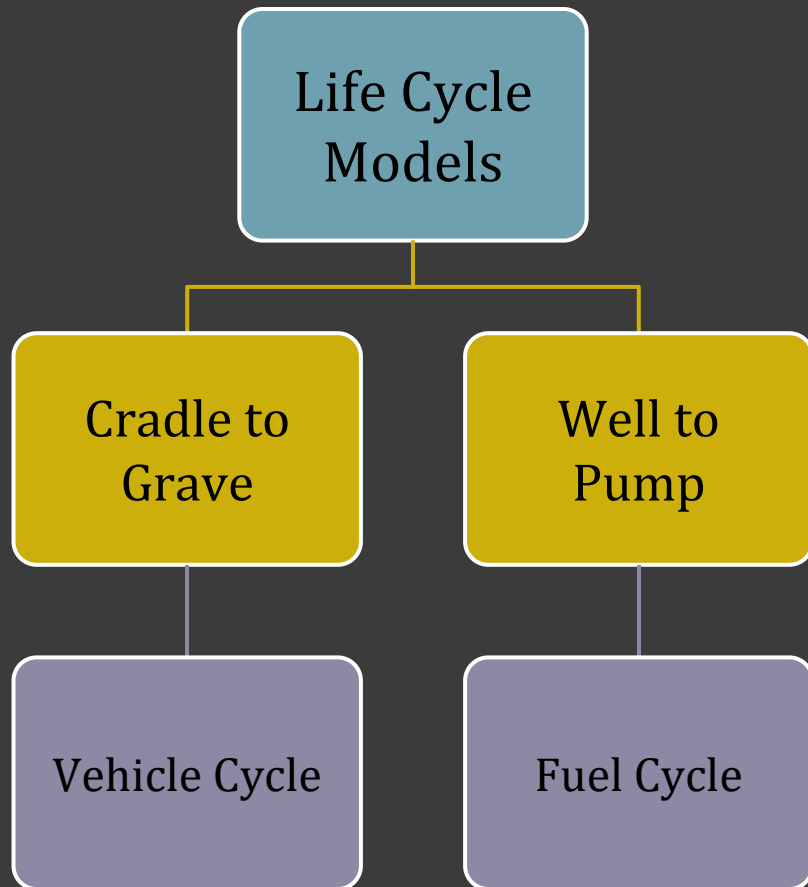
40%



50%



Sustainability and LCA



- i. Crisis
- ii. Sustainability
- iii. **Framework**
- iv. Analysis
- v. Results
- vi. Conclusion

The Sustainability Framework ^(1/3)

Goals and dimensions of a transportation system

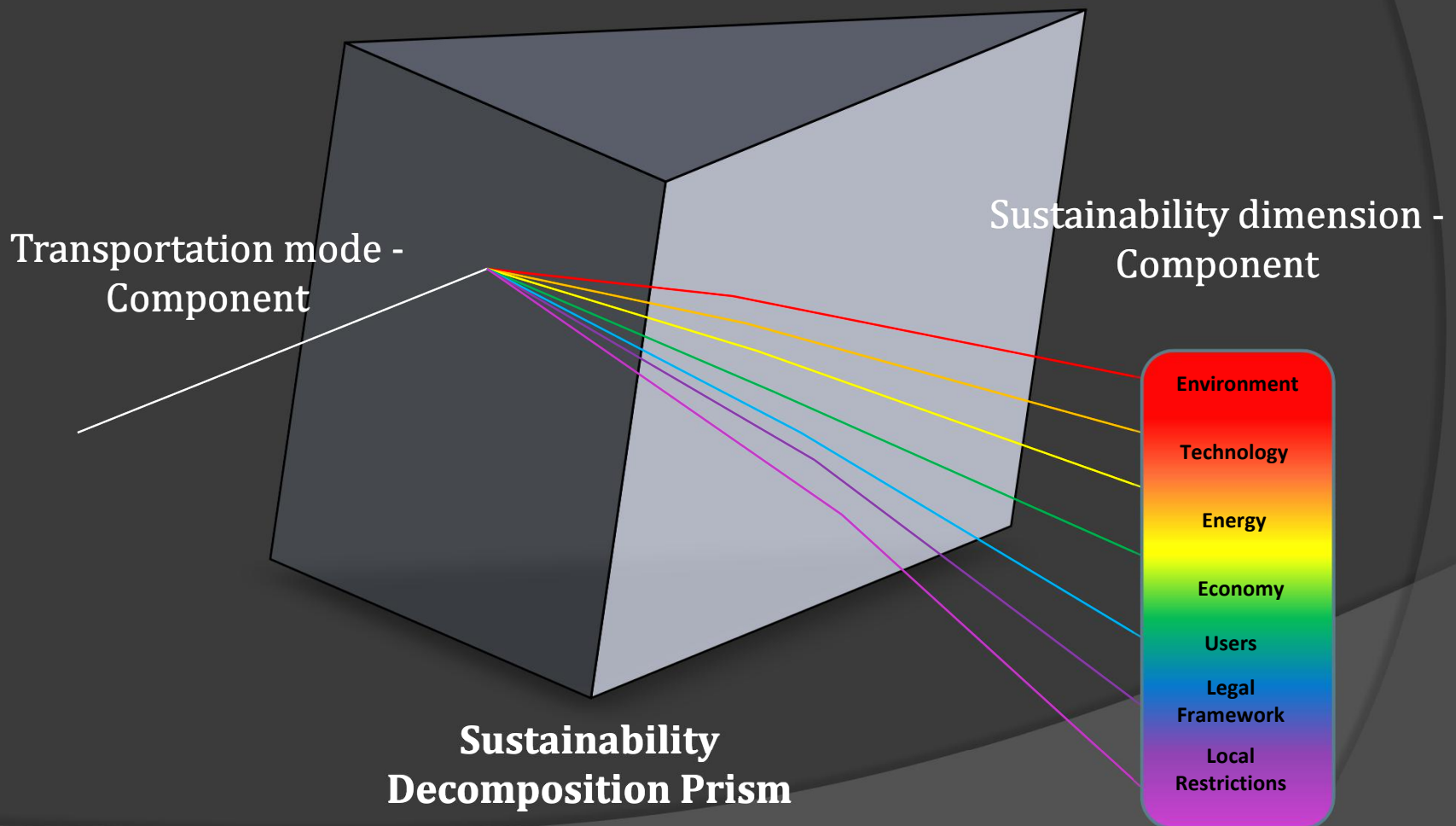
The 7 goals seek to:

1. Minimize environmental impact
2. Maximize technology performance to help people meet their needs
3. Minimize energy consumption
4. Maximize and support a vibrant economy
5. Maximize users' satisfaction
6. Comply with legal framework
7. Comply with local restrictions

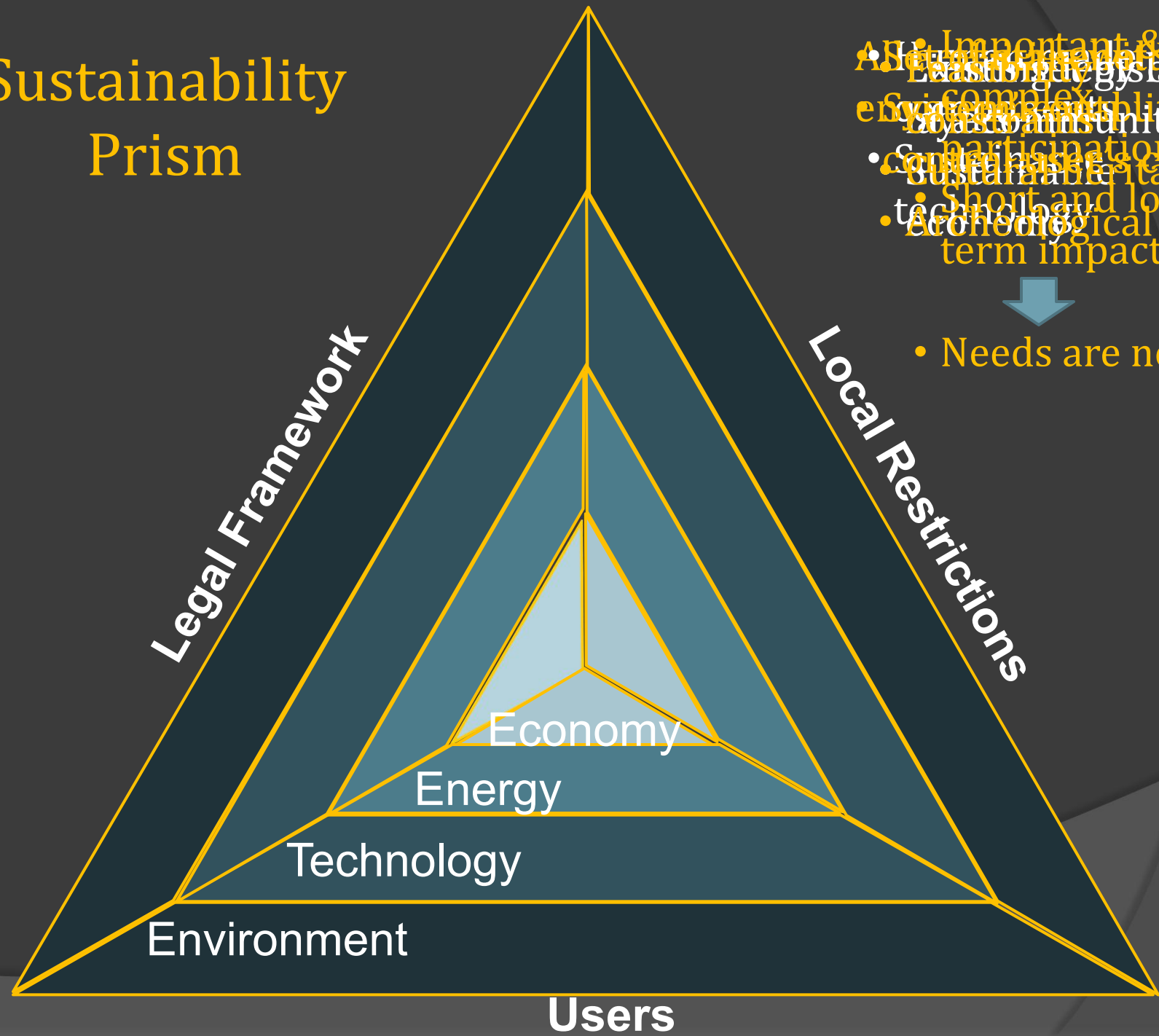
The 7 dimensions:

1. Environment
2. Technology
3. Energy
4. Economy
5. Users (and other stakeholders)
6. Legal framework
7. Local restrictions

The Sustainability Framework (2/3)



Sustainability Prism



- Important & difficult
- Existing legislation
- System complexity
- System uncertainty
- Participation choice
- Sustainable choice
- Short and long term impacts
- Technology
- Archaeological sites



- Needs are not met

Sample Applications

- ⦿ Transportation systems
- ⦿ Transportation modes

Other applications

- ⦿ Hydroelectric, coal, nuclear plants
- ⦿ Wind, solar power generation
- ⦿ Construction
- ⦿ Waste treatment
- ⦿ Other infrastructure

Focus → Urban transportation modes

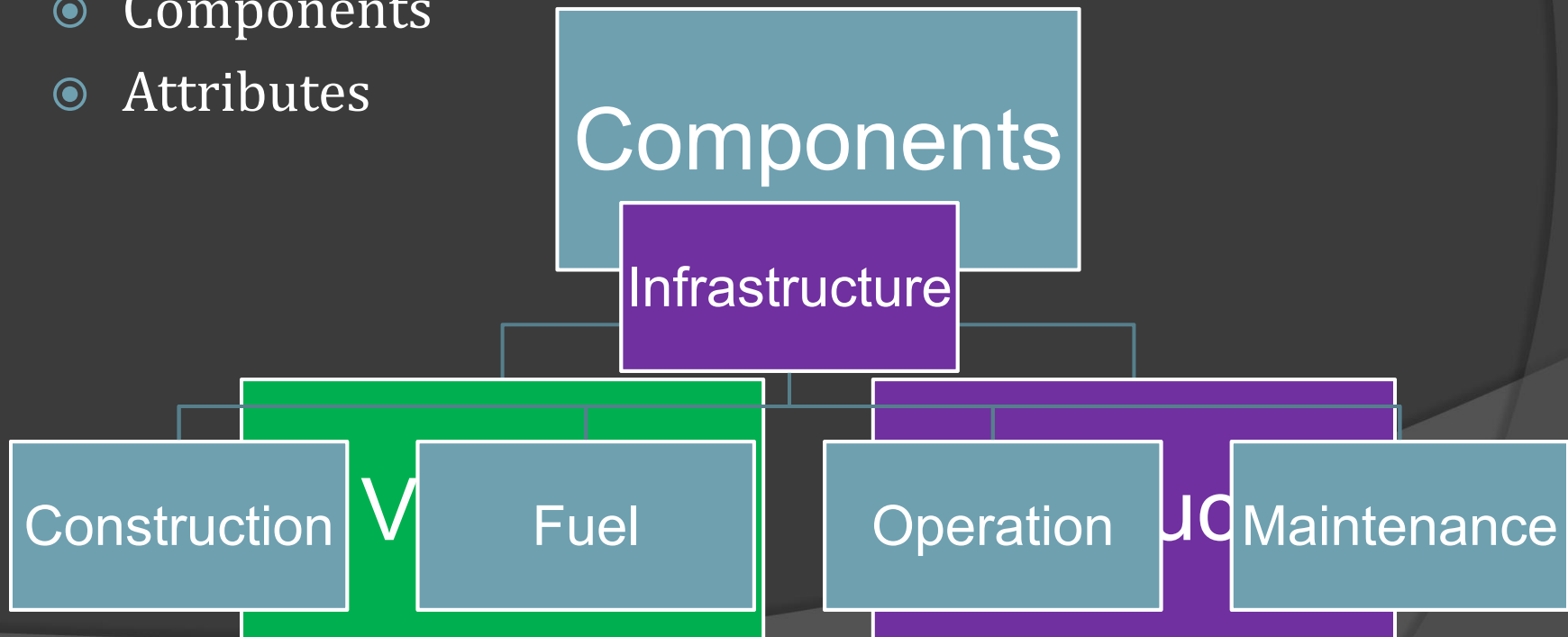
The Sustainability Framework ^(3/3)

Adjusted to assess sustainability in transportation

Urban transportation mode

- ⦿ System operator
- ⦿ Traveler
- ⦿ Components
- ⦿ Attributes

Different technologies and
fuel types

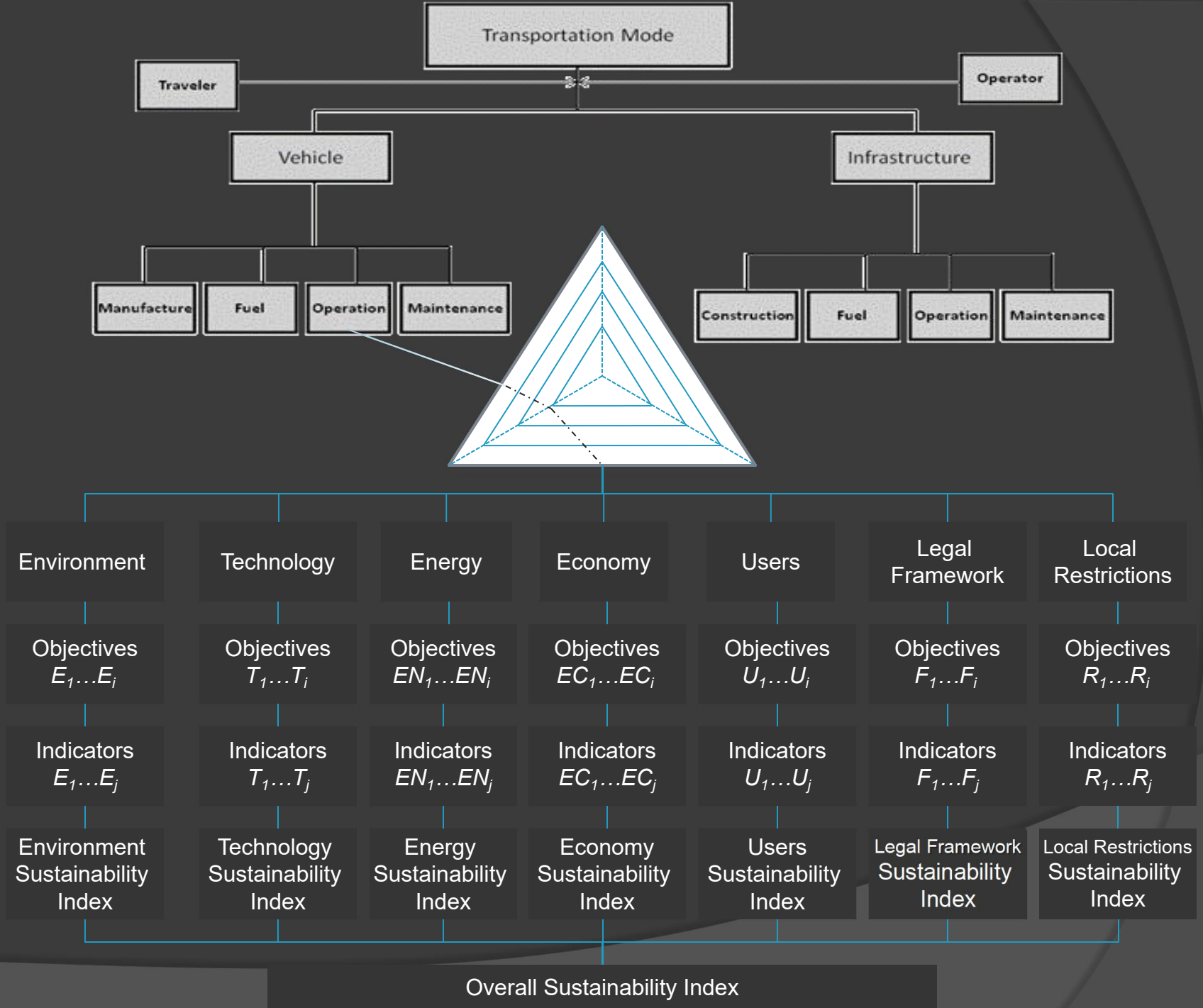


Sustainability Indicators ^(1/2)

From literature developed indicators for sustainable transportation assessment grouped under 4 sustainability dimensions:

1. Transportation system performance
2. Environment
3. Society
4. Economy

These sustainability dimensions are captured by the sustainable transportation goals described in the two fundamental definitions on sustainable transportation provided by the WCED (1987) and the (ECMT 2001)



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Assumptions

- ⦿ All vehicles use the same infrastructure
- ⦿ Indicators focus on the component vehicle, and 5 sustainability dimensions:
 1. Environment
 2. Technology
 3. Energy
 4. Economy
 5. Users

The remaining two dimensions (legal framework and local restrictions) are imposed by communities and they are applicable only to the deployment of specific transportation projects

Transportation Vehicles

1. Internal Combustion Engine Vehicle or **ICEV** (2010 Toyota Camry LE)
2. Hybrid Electric Vehicle or **HEV** (2010 Toyota Prius III)
3. Fuel Cell Vehicle or **FCV** (2009 Honda Clarity FCX)
4. Electric Vehicle or **EV** (2011 Nissan Leaf)
5. Plug-In Hybrid Vehicle or **PHEV** (2011 Chevrolet Volt)
6. Gasoline Pickup Truck or **GPT** (2010 Ford F-150 base)
7. Gasoline Sports Utility Vehicle or **GSUV** (2010 Ford Explorer Base)
8. Diesel Bus or **DB** (New Flyer 40' Restyled)
9. Bus Rapid Transit or **BRT** (New Flyer 60' Advanced Style BRT)
10. Car-sharing or **CS** program with **ICEV** (2010 Toyota Camry LE)
11. Car-sharing or **CS** program with **HEV** (2010 Toyota Prius III)

Light Duty EVs Sold

Year	US Sales	% of World
2010+2011	17,425	
2012	52,607	
2013	97,507	
2014	122,438	38%
2015	116,099	21%
2016	158,614	20%
2017	199,826	22%

2017 Comparable US Market *Toyota* Cars

Type	ICEV	HEV	PHEV	FCV
Model	<i>Corolla LE</i>	<i>Prius II</i>	<i>Prius Prime</i>	<i>Mirai</i>
MSRP	\$19,000	\$25,000	\$28,000	\$57,500
Tax Credit	n.a.	n.a.	\$7,500	\$7,500
MPG/MPGe	32	54	54	67
Range (miles)	~410	~600	~640	~310
0-60 mph in sec.	9.8	10.5	10.9	9.0
Fuel stations	167,000	167,000	15,500	35 (all in CA)

Sample of US Market Alternative Fuel Vehicles

Year	Brand	Model	Type	Approx. Price in US \$	Curb Weight (lb)	Battery Type	Battery KWh	City mpg/MPGe	Electric-only Range (miles)	0-60 mph (sec.)
2017	BMW	i3	EV	\$44,450	2635	Li-ion	33	na/137	97	6.5
2017	Chevrolet	Bolt	EV	\$37,495	3580	Li-ion	60	na/128	238	6.3
2010	Chevrolet	Volt	EV	\$34,095	3543	Li-ion	18.4	42/106	420	8.8
2017	Ford	Focus	EV	\$29,120	3640	Li-ion	33.5	na/118	100	9.9
2014	Honda	FIT EV	EV	\$36,625	3252	Li-ion	20	na/132	82	8.6
2017	Mitsubishi	i-MiEV	EV	\$24,400	2552	Li-ion	16	na/121	66	13
2016	Nissan	LEAF S	EV	\$30,680	3307	Li-ion	24	na/99	84	10.4
2016	Nissan	LEAF SV	EV	\$34,200	3391	Li-ion	30	na/124	107	10.2
2012	Tesla	Model S	EV	\$69,500	4150	Li-ion	40	na/88	160	5.6
2017	Tesla	Model S	EV	\$74,500	4647	Li-ion	75	na/97	265	5.1
2016	Tesla	Model X 90D	EV	\$95,500	5271	Li-ion	90	na/90	250	4.8
2017	Honda	Clarity	FCV	Lease	4148	Li-ion	1.7	69/69	366	8.1
2017	Toyota	Mirai	FCV	\$57,500	4078	NiMH	1.6	67/67	300	9
2016	Chevrolet	Malibu	HEV	\$28,750	3388	Li-ion	1.5	49/na	na	7.4
2017	Ford	C-MAX SE	HEV	\$24,175	3640	Li-ion	7.6	42/na	na	8.1
2017	Ford	Fusion S	HEV	\$25,295	3668	Li-ion	1.4	43/na	na	9.1
2017	Honda	Accord	HEV	\$29,605	3483	Li-ion	1.3	49/na	na	6.9
2016	Honda	CR-Z	HEV	\$20,295	2650	Li-ion	0.6	36/na	na	9.3
2017	Toyota	Avalon	HEV	\$37,300	3461	NiMH	1.6	40/na	na	7.4
2017	Toyota	Camry	HEV	\$27,625	3240	NiMH	1.6	42/na	na	7.2
2017	Toyota	Highlander	HEV	\$37,230	4134	NiMH	1.9	29/na	na	7.0
2017	Toyota	Prius II	HEV	\$24,685	3075	NiMH	1.2	54/na	na	10.2
2017	Toyota	Prius c	HEV	\$20,150	2530	NiMH	0.9	48/na	na	10.9
2017	Toyota	Prius v	HEV	\$26,675	3340	NiMH	1.3	43/na	na	10.3
2017	BMW	i8	PHEV	\$143,400	3394	Li-ion	7.1	28/76	15	4.2
2017	BMW	330e	PHEV	\$44,100	3900	Li-ion	7	30/71	14	5.9
2017	Toyota	Prius Prime	PHEV	\$27,965	3365	Li-ion	9	54/133	25	10.9

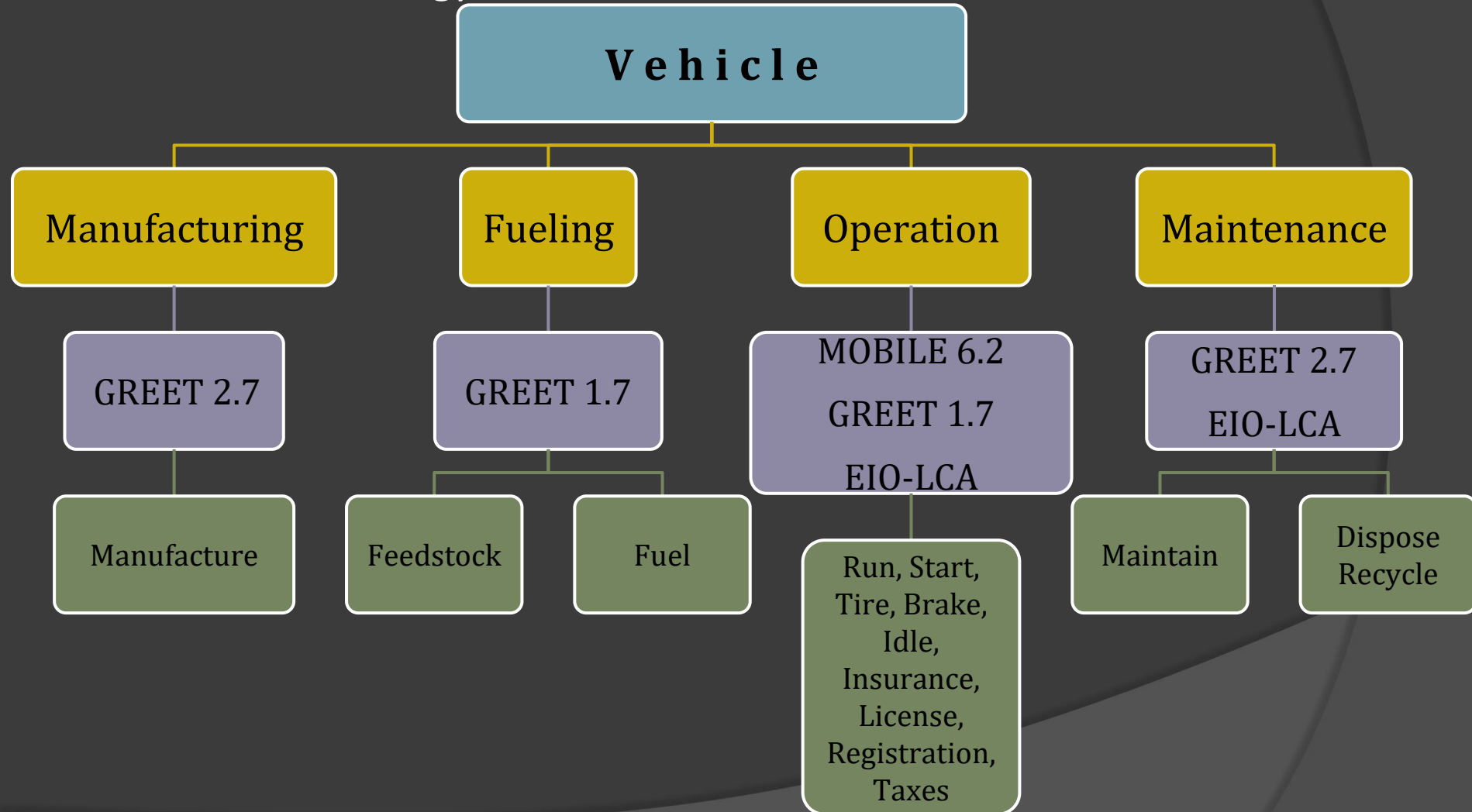
Vehicle Characteristics

		ICEV	HEV	FCV	EV	PHEV	GPT	GSUV	DB	BRT	CS	CS
		Camry	Prius	Clarity	Leaf	Volt	F-150	Explorer	New flyer	New flyer	Camry	Prius
Weight	Lbs	3,307	3,042	3,582	3,500	3,781	5,319	4,509	26,000	49,000	3,307	3,042
Average occupancy	passengers	1.15	1.15	1.15	1.15	1.15	1.10	1.40	10.50	23.90	4.58	4.58
Average lifetime	years	10.6	10.6	15.0	15.0	15.0	9.6	9.6	12.0	12.0	2.0	2.0
Average annual miles	miles	11,300	11,300	11,300	11,300	11,300	11,300	11,300	41,667	41,667	18,000	18,000
Lifetime miles	miles	119,780	119,780	169,500	169,500	169,500	108,480	108,480	500,000	500,000	36,000	36,000
Cost to buy (MSRP)	\$ US dollars	\$22,225	\$23,050	\$48,850	\$32,780	\$40,000	\$22,060	\$28,190	\$319,709	\$550,000	\$22,225	\$23,050
Fuel Price	\$ per U.S.	\$2.85	\$2.85	\$4.90*	\$0.16**	\$2.85	\$2.85	\$2.85	\$2.94	\$2.94	\$2.85	\$2.85
(Jan. 2010 - W.Coast)	gallon											

Note: (*) per kg, (**) per kWh

Life Cycle Models

Emissions and Energy



Environment

Sustainability Dimension	Goal	Objective	Indicator
Environment	Minimize environmental impact	Minimize global warming	Carbon Dioxide - CO ₂ Methane - CH ₄ N ₂ O GHG
		Minimize air pollution	Volatile Organic Compound Carbon Monoxide - CO Nitrogen Oxides - NO _x Particle Matter - PM ₁₀ Sulphur Oxides - SO _x
		Minimize noise	Noise
		Minimize externalities on living humans and species	Health

Technology

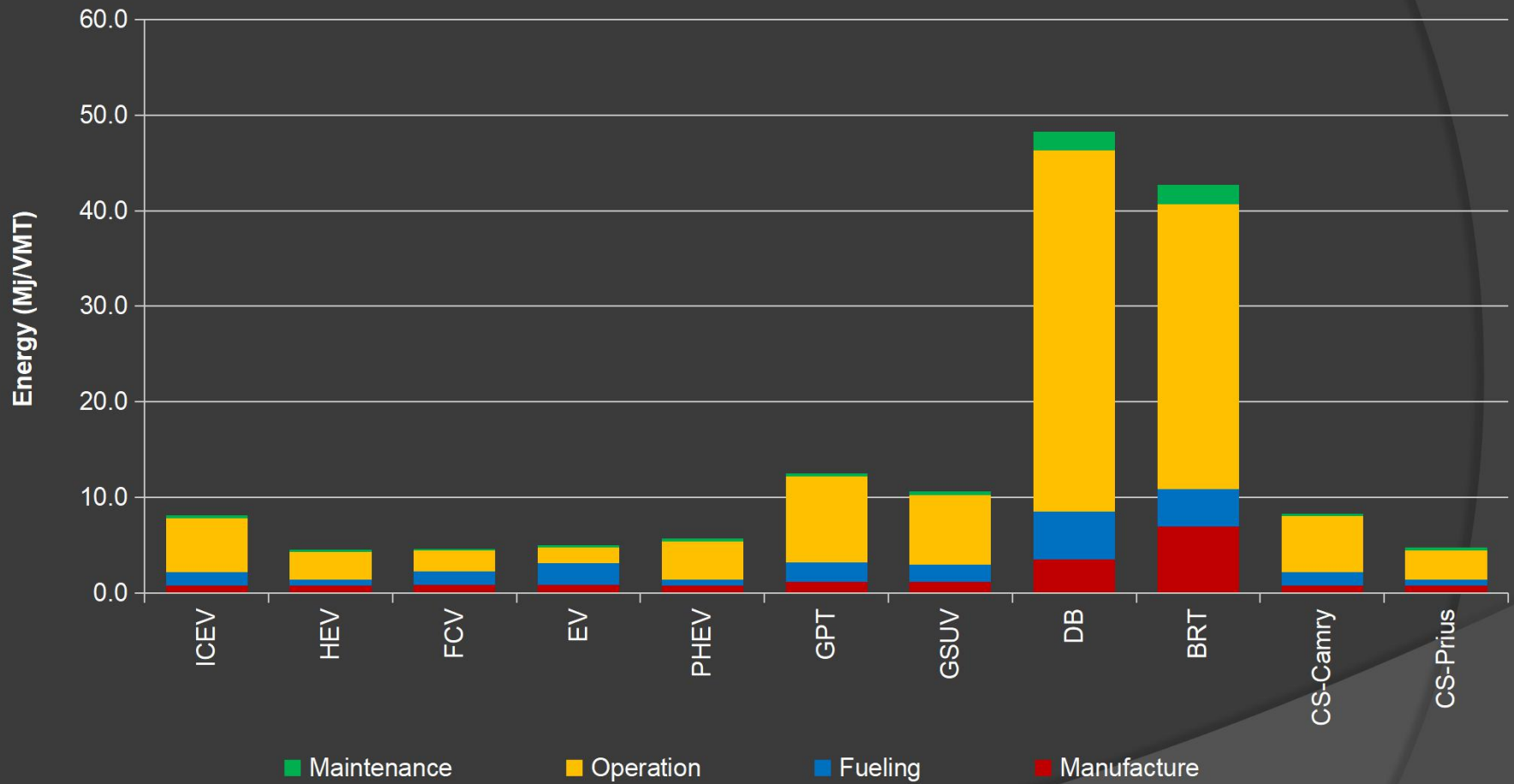
Sustainability Dimension	Goal	Objective	Indicator
Technology	Maximize technology performance to help people meet their needs	Maximize vehicle lifetime	Vehicle lifetime Upgrade potential
		Maximize used resources	Capacity
		Minimize time losses	Fuel frequency Maintenance frequency
		Minimize land consumption	Vehicle storage
		Maximize supply	Supply
		Maximize mode choices for all users	Feasibility of use by social excluded groups Readiness
		Maximize vehicle performance	Engine power

Energy

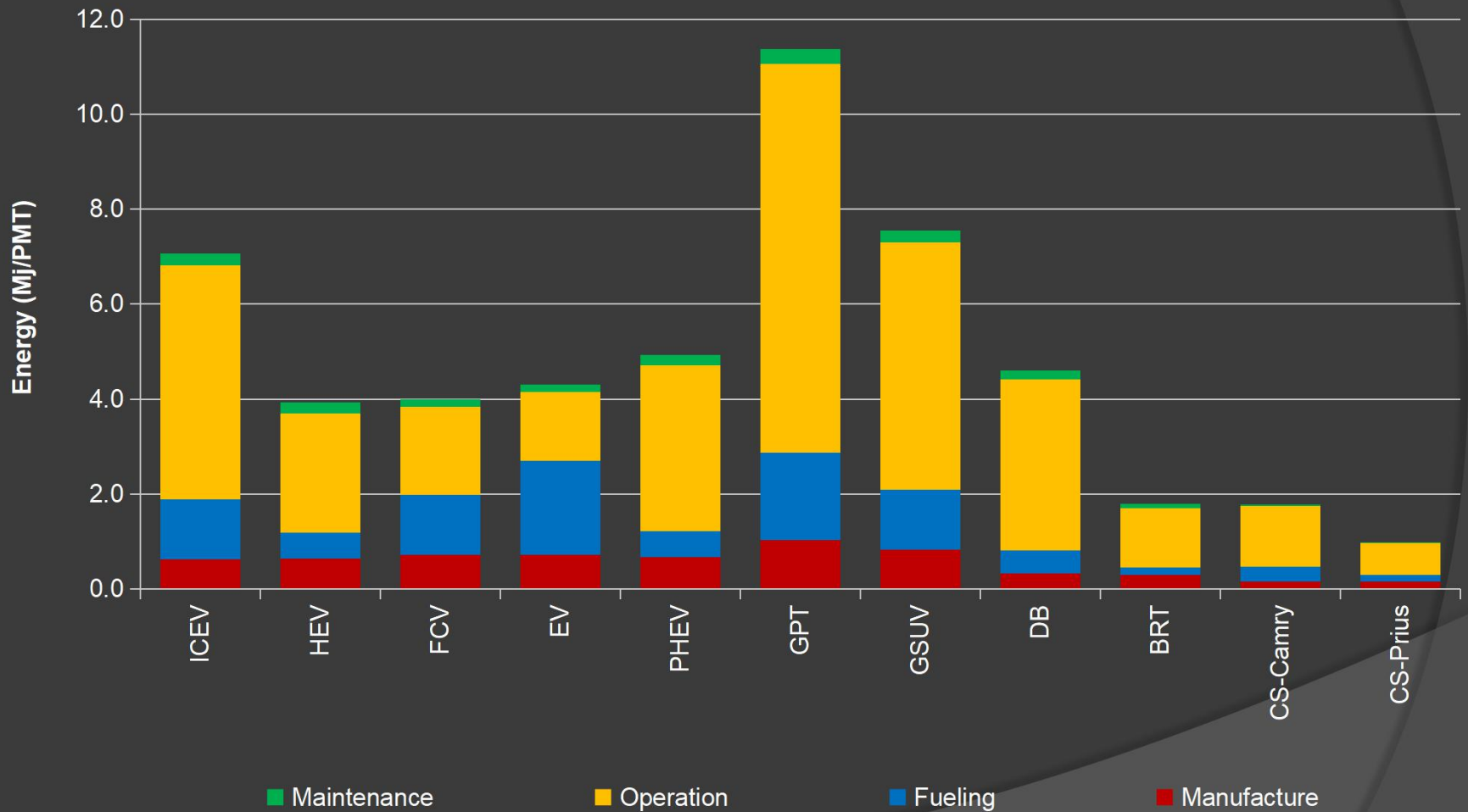
Sustainability Dimension	Goal	Objective	Indicator
Energy	Minimize energy consumption	Minimize energy consumption	<div>Manufacturing energy</div> <div>Fueling energy</div> <div>Operation energy</div> <div>Maintenance energy</div>

- i. Crisis
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Energy Consumption per VMT



Energy Consumption per PMT













Economy

Sustainability Dimension	Goal	Objective	Indicator
Economy	Maximize and support a vibrant economy	Reduce cost requirements	Cost Property damage
		Minimize parking requirements	Parking cost
		Minimize costs for the community	Safety cost
		Minimize governmental support	Subsidy
		Promote welfare	Job opportunities

Users

Sustainability Dimension	Goal	Objective	Indicator
Users	Maximize users satisfaction	Maximize transportation performance	Mobility
			Demand
			Global availability
			Reasonable availability
			Delay
			Reliability
			Safety
		Improve accessibility	Equity of access
		Maximize user comfort	Leg room
			Cargo space
			Seated probability
			Fueling opportunities

Urban Mode Sustainability Scores

Sustainability Dimensions											
	ICEV	HEV	FCV	EV	PHEV	GPT	GSUV	DB	BRT	CS	CS
	Camry	Prius	Clarity	Leaf	Volt	F-150	Explorer	New flyer	New flyer	Camry	Prius
Environment	0.483	0.637	0.803	0.642	0.606	0.145	0.492	0.717	0.860	0.907	0.959
Technology	0.450	0.500	0.408	0.553	0.471	0.387	0.489	0.628	0.669	0.561	0.590
Energy	0.388	0.572	0.545	0.462	0.541	0.019	0.324	0.673	0.908	0.956	0.999
Economy	0.341	0.385	0.485	0.557	0.454	0.193	0.354	0.326	0.486	0.578	0.561
Users	0.344	0.347	0.291	0.129	0.354	0.429	0.402	0.250	0.228	0.344	0.347
Overall Sustainability Index	40.1%	48.8%	50.6%	46.8%	48.5%	23.4%	41.2%	51.9%	63.0%	66.9%	69.3%
Ranking	10	6	5	8	7	11	9	4	3	2	1

- i. Crisis
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Conclusion

(1/4)

- ◎ Transportation policies should promote a sustainable transportation system in the short and long term
- ◎ A dynamic sustainability framework must include the latest data of a transportation system...
 - fuel types, stations and costs, insurance rates, fees and taxes, vehicle weight, fuel efficiency, vehicle mileage, battery capacity
- ◎ Be sensitive to local policies ...
 - fuel costs, parking cost, road pricing charges, etc. are necessary to support transportation policy and planning

Conclusion

(2/4)

- ⦿ In the short term, there are no barriers to increasing the penetration of HEV
- ⦿ HEV has the second best sustainability performance
- ⦿ In the long term electric drive and fuel cell vehicles have the potential to reduce environmental impact
- ⦿ Car ownership per household in first world countries will decrease ...
 - due to aging and lower birth rates, the fading of the baby boomer effect in the U.S., restrictions of certain types of automobiles (for pollution or congestion reasons) and transportation-as-a-service (TaaS) with driver operated (e.g., DiDi, Lyft, Uber) and autonomous taxis

Conclusion

(3/4)

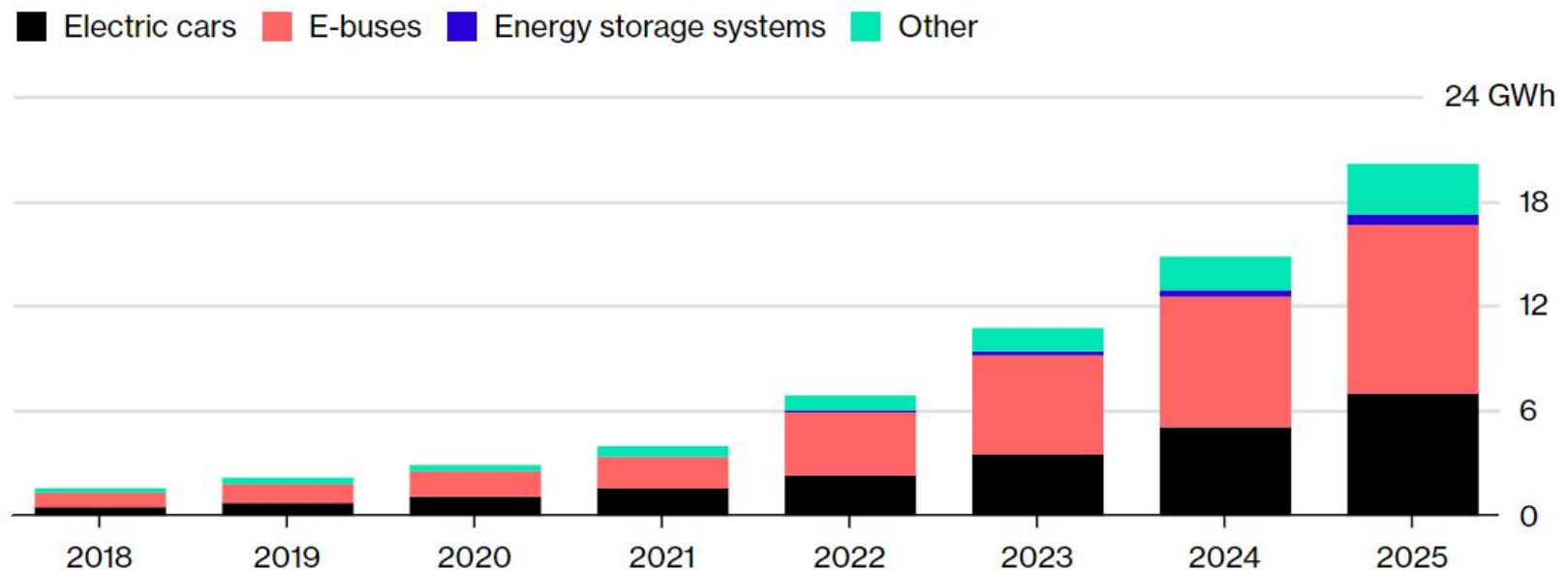
- ⦿ EV and HEV are becoming more capable and are particularly suitable for polluted environments
- ⦿ EV and HEV have the potential to become the dominant type of light duty passenger service vehicle in large urban areas
- ⦿ This depends primarily on their purchase price, and regulations favoring them

Conclusion

(4/4)

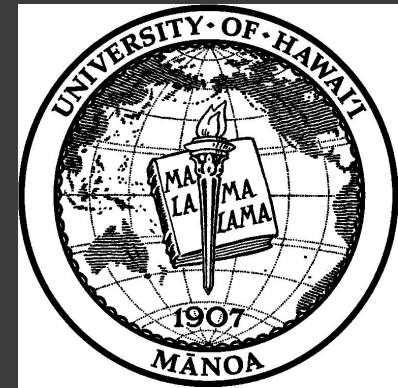
- As long as gasoline-powered vehicles offer strong performance, rich technological content and good safety for \$25,000 or less (~2017 U.S. \$), EVs with the same range and content priced above \$25,000 (which is the

E-bus batteries will account for the bulk of second-life capacity through 2025



Source: Circular Energy Storage

Thank You!



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