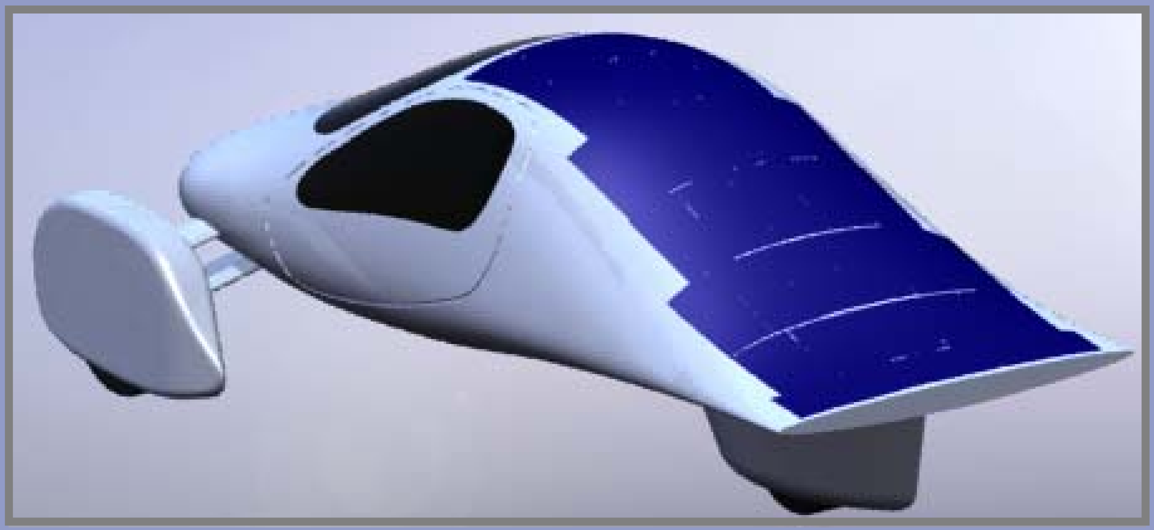
2.626 Fundamentals of Photovoltaics
Fall 2008

The Role of PV in the Electrification of the Automobile (PV4EV)



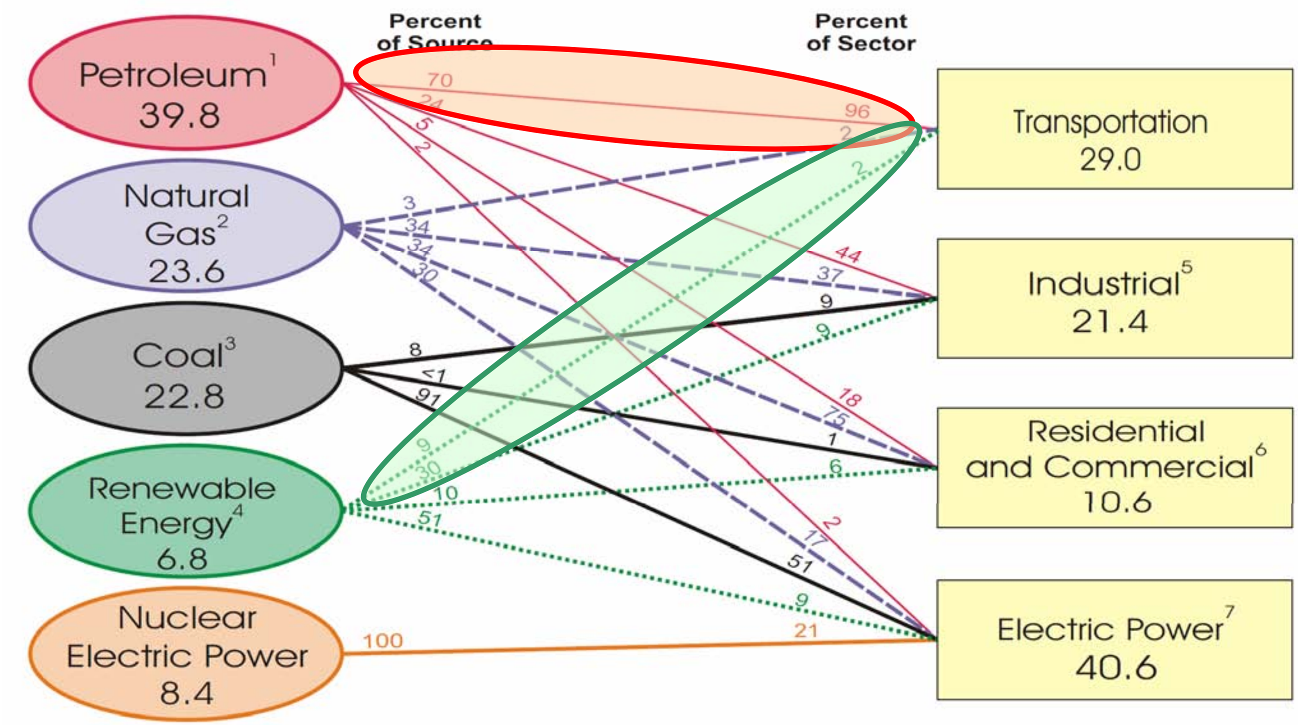
Outline

- Motivation
- EV Background
- Using PV for EV
  - Integrated EV/PV
  - Charging Stations
    - Overview
    - Architecture
    - Design Results
- Paying for it / LCA
- Conclusions

Motivation

Personal vehicles in the U.S. account for 44% of ***oil*** consumption and 22% of CO_2 emissions

U.S. Primary Energy Consumption by Source and Sector (Quadrillion BTU)



[EIA, Annual Energy Review, 2008 (DOE/EIA-0384(2007))]

PV for EVs is a unique opportunity to address transportation's oil consumption and CO2 emissions

- Motivation/ Background
- Integrated PV
- Charging stations
- Paying for it & LCA
- Conclusions

Background on Electric Vehicles (EVs)

EVs are more efficient than conventional vehicles but suffer from lower range, higher initial cost, and long charge times

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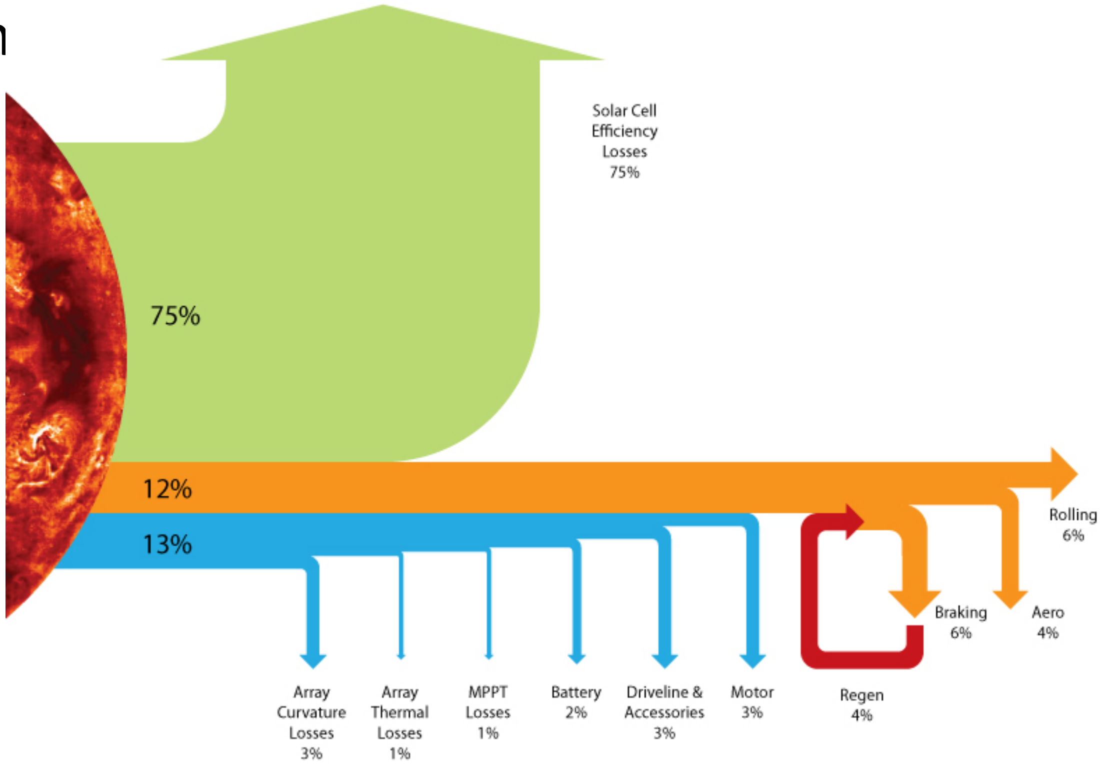
Berry, Irene, et al. "What's the Deal with Hybrid and Electric Cars?" Cambridge, MA: MIT Electric Vehicle Team, January 20, 2009.

We considered three types of EVs (all mid-size sedans): a 50-mile EV, a 150-mile EV, and a 50-mile Plug-in HEV (PHEV).

Integrated PV-EV

- One way that PV can be used for transportation is in an integrated PV vehicle.
- In this application, system efficiency is important!



Integrated PV-EV

- Estimated range of integrated PV electric cars in Massachusetts and California.
- Used Aptera Typ1-e as example.
- Considered Range for 2 different PV technologies
  – Monocrystalline Si and Multijunction GaAs

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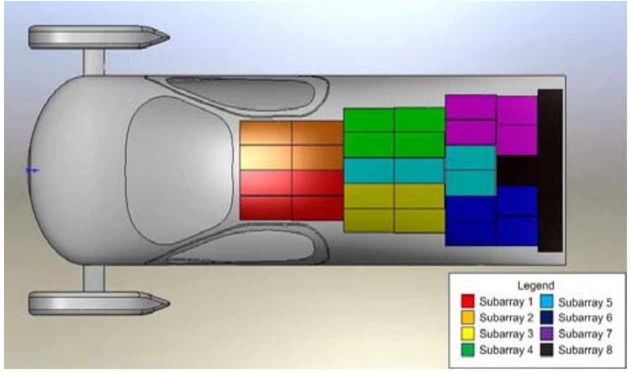
	Aptera Typ1-e	Toyota Prius
Drag Coefficient	0.11	0.26
Frontal Area	1.5 m^2	2.3 m^2
Mass	1480 lbs	2932 lbs
All - Electric Range	120 Miles	8 Miles
Energy Consumption	92.8 Wh/mi	325 Wh/mi

Integrated PV-EV

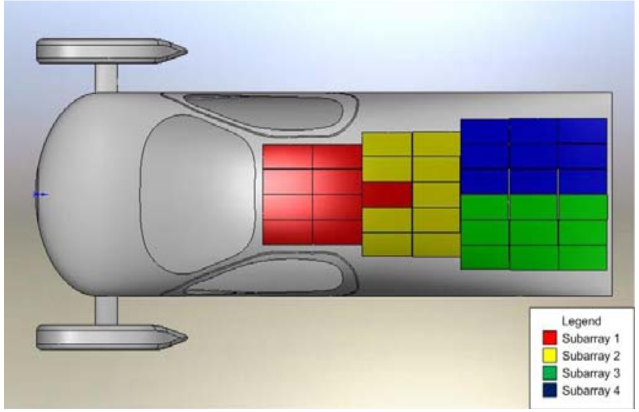
- Calculated range of vehicle using Matlab script and imported CAD data.
  - Calculation included losses due to curvature and module layout.

	Boston		LA	
	Si	GaAs	Si	GaAs
Average Daily Range(mi)	11.1	18.0	13.9	22.3
Cost per Mile Range($/mi)	$3378	$5300	$2698	$4278

- Conclusions
  - Range for PV integrated car is limited, will need to be charged from an external source.



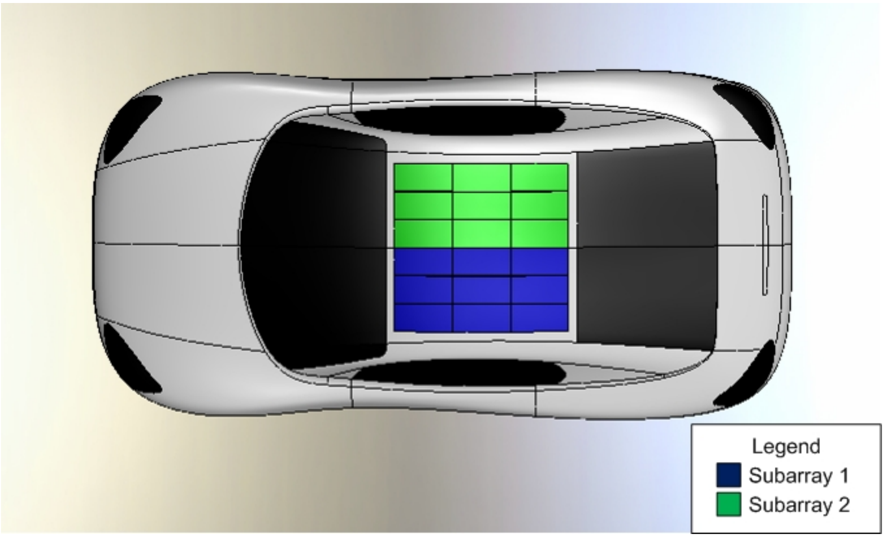
GaAs Array



Si Array

Integrated PV-EV

- Calculated energy available and range of traditional EV retrofitted with roof mounted Si solar panels.
  - Calculations same as previous case.
- Conclusions
  - Range associated with a roof panel is very limited.
  - Roof panel useful to operate systems when the car is off. (e.g. Air Conditioning)



	Boston	LA
Average Daily Range(mi)	2.6	3.3
Cost per Mile Range($/mi)	$ 2211	$ 1742

Charging station

Overview

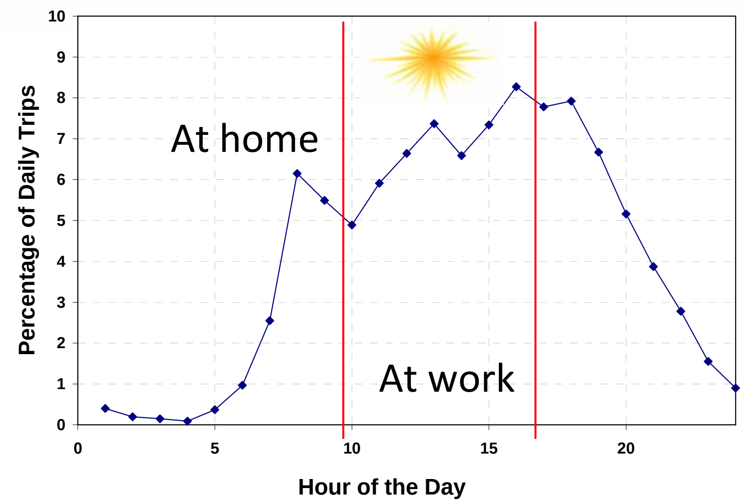
Image from EV World.

1st configuration	2nd configuration	3rd configuration
On grid	On grid	Off grid
With storage	Without storage	With storage
+ never short of supply	+ never short of supply	- unreliability of the supply
- expensive storage	+ cheaper maintenance	- even more expensive storage

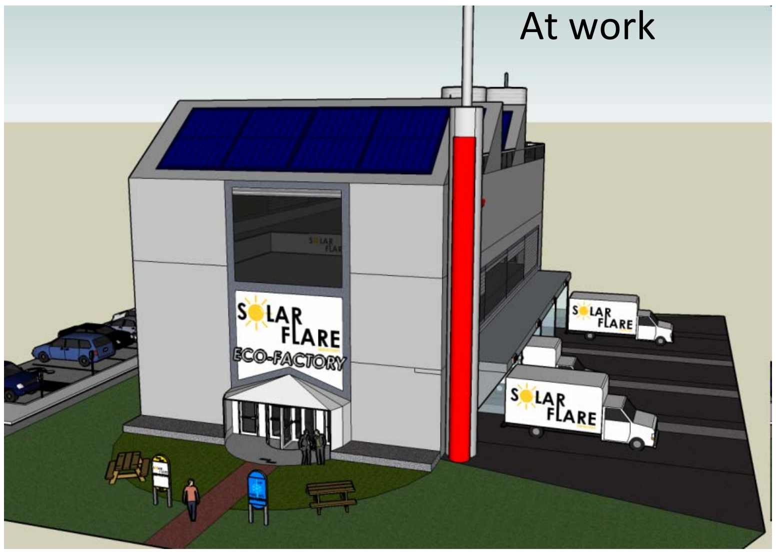
Charging station

Locations

At home

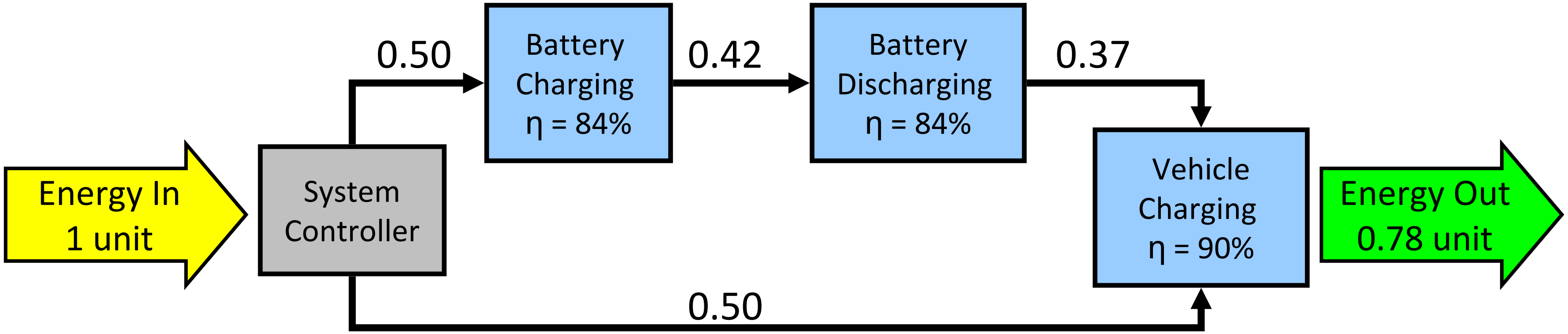


Public stations



Off-grid with battery storage

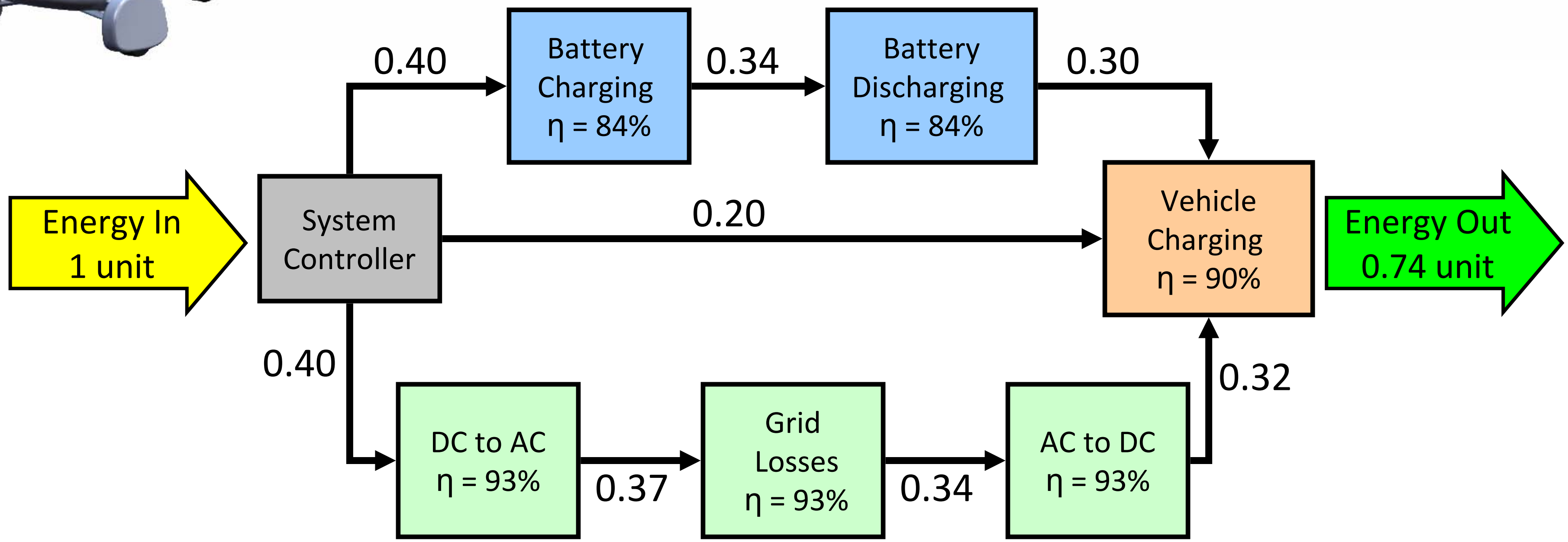
Architecture



- Station Efficiency = 78%
- Substantial charging during day
- Appropriate for at work charging station
  - 50% of electricity goes directly to car

On-grid with battery storage

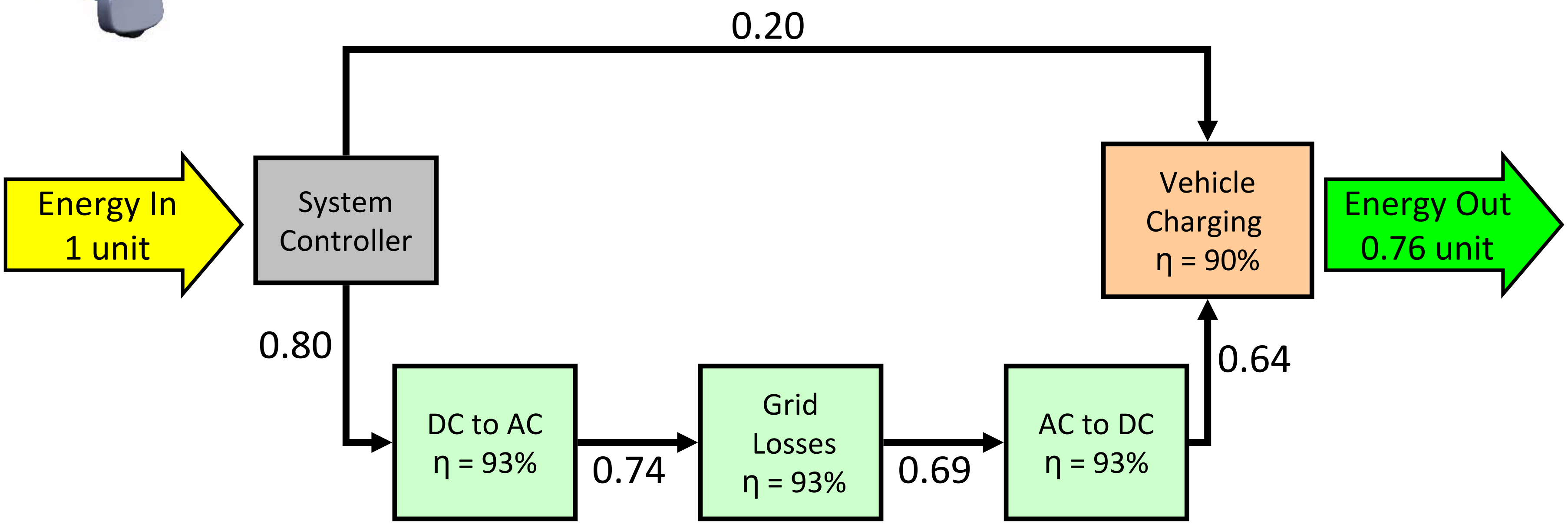
Architecture



- Station Efficiency = 74%
- Flexible station architecture
  - Appropriate for at work or home charging station

On-grid without battery storage

Architecture



- Station Efficiency = 76%
- Appropriate for home charging station
  - Majority of charging done at night

Charging Station Costs

Results

	Boston		LA	
	$/mile	Total Cost	$/mile	Total Cost
Off Grid with Battery	$0.116	$841k	$0.099	$720k
On Grid with Battery	$0.102	$743k	$0.073	$533k
On Grid without Battery	$0.083	$605k	$0.055	$401k

- 15 car charging station
- All station component costs included
- Land costs are substantial - not included here
- 25-mpg with $2.50/gal fuel → $0.10/mile

Subsidies

Motivation/ Background
Integrated PV
Charging stations
Paying for it & LCA
Conclusions

- Federal
  - Solar: 30% tax credit, no cap (starting 2009)
  - EV: $2,500 plus $417 for each kWh battery capacity above 4kWh capped at $7,500
- California
  - $2.50/W investment rebate up to $50kW_p$
  - $0.39/kWh for first 5 years greater than $50kW_p$
  - No cap (but stepped down at unknown times)
- Massachusetts
  - 15% investment tax credit, capped at $1,000
  - $0.03/kWh production tax credit for the first three years of operation
  - $3/W capacity based incentive, capped at 5kW residential, 500kW non-residential

Subsidies – EV

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Subsidies – Solar: Residential

- Federal
  - **Solar: 30% tax credit, no cap (starting 2009)**
  - EV: $2,500 plus $417 for each kWh battery capacity above 4kWh capped at $7,500
- California
  - **\$2.50/W investment rebate up to 50kW$_p$**
  - **\$0.39/kWh for first 5 years greater than 50kW$_p$**
  - No cap (but stepped down at unknown times)
- Massachusetts
  - 15% investment tax credit, capped at $1,000
  - $0.03/kWh production tax credit for the first three years of operation
  - **$3/W capacity based incentive, capped at 5kW residential, 500kW non-residential**

Subsidies – Solar: Commercial

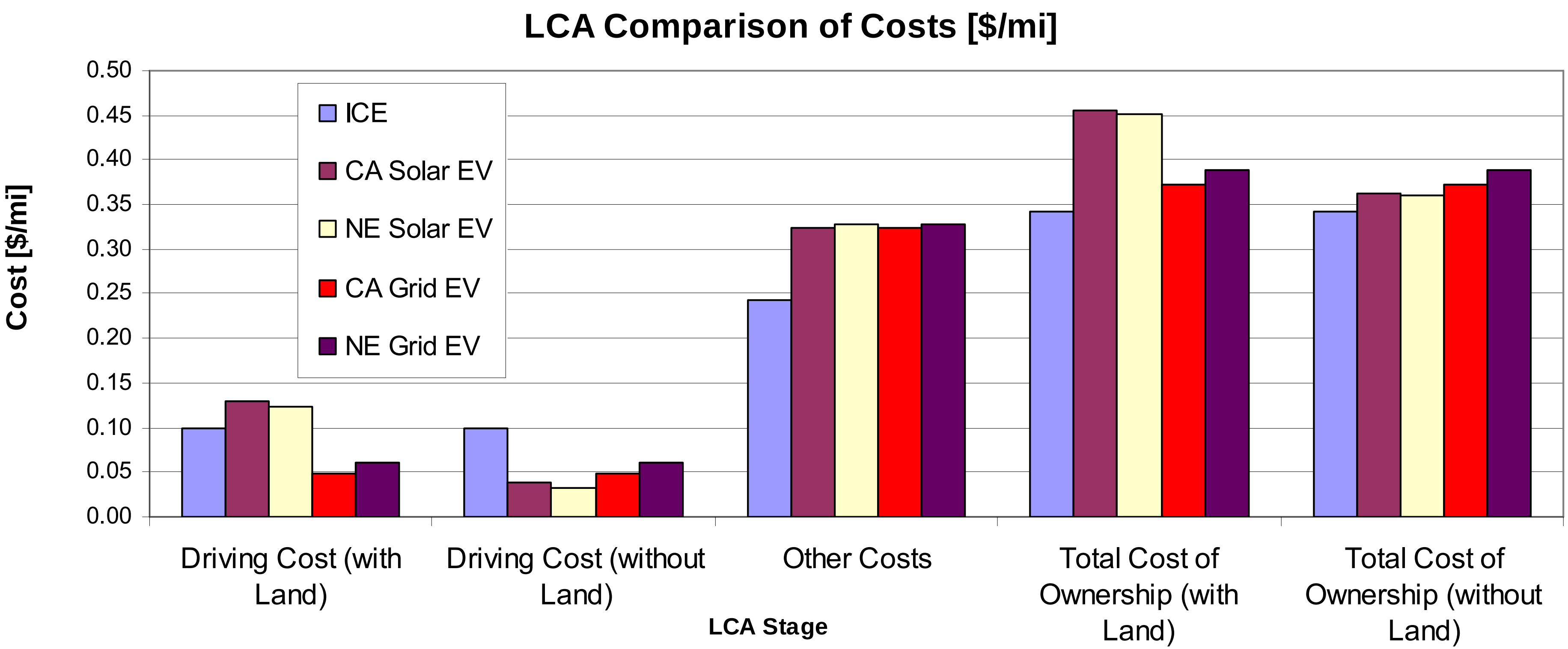
- Federal
  - **Solar: 30% tax credit, no cap (starting 2009)**
  - EV: $2,500 plus $417 for each kWh battery capacity above 4kWh capped at $7,500
- California
  - **$2.50/W investment rebate up to 50kW$_p$**
  - **$0.39/kWh for first 5 years greater than 50kW$_p$**
  - No cap (but stepped down at unknown times)
- Massachusetts
  - 15% investment tax credit, capped at $1,000
  - $0.03/kWh production tax credit for the first three years of operation
  - **$3/W capacity based incentive, capped at 5kW residential, 500kW non-residential**

Effect on LCOE

- Subsidies are comparable
- Subtracts about $0.12/kWh from LCOE

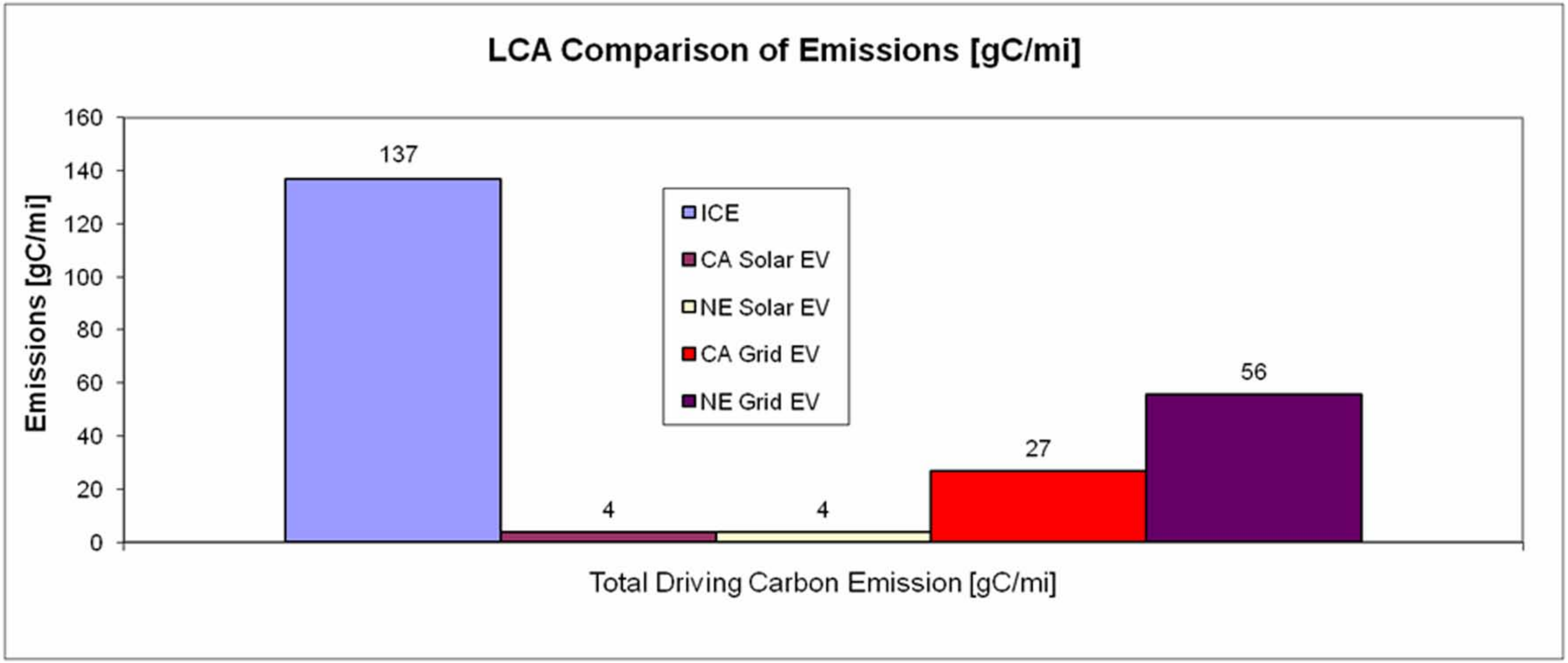
- Don’t have to pay for land
  - LCOE = ~$0.10/kWh (compared to ~$0.22/kWh)
- Have to pay for land
  - LCOE = ~0.36/kWh (compared to ~$0.48/kWh)

LCA - Cost Comparisons



Location	**Massachusetts**			**California**		
Vehicle	**EV50**	**PHEV50**	**EV150**	**EV50**	**PHEV50**	**EV150**
EV Payback [years]	0.4	0.4	15.1	0.4	0.5	17.0
Percentage of Vehicle Life	3.2%	3.4%	121.8%	3.5%	3.8%	136.9%

LCA - Emissions Comparisons



Conclusions

Motivation/ Background

Integrated PV

Charging stations

Paying for it & LCA

Conclusions

- PV4EV is feasible for many US drivers, but large economic incentives are necessary
  - Full performance EVs meet commuting needs

PV4EV	Capital Cost	Convenience	CO_2
vs. ICE	↑	↓	↓ 12x
vs. grid EV	↔	↔	↓ 3~6x

- PV integrated EV not practical or economical
  - Higher cost, lower performance
  - No advantages over PV charged EVs

Discussion

- Benefits are known for PV, EV
  - Economic incentives in place
  - Environmental benefits, moral superiority
- Need to overcome convenience tradeoffs with other incentives
  - Company or city owned charging stations
    - Shift capital costs away from drivers
  - Alt. benefits: VIP parking, free charging

Future Work

- Uncertainty in LCA analysis
- Other environmental measures
- Impact of PV4EV on a large scale

Questions?

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