

# Using Electric Vehicles for Grid-Connected Storage

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**Energy and Nanotechnology-Storage and The Grid**

**Rice University—16 Nov 2005**

# Energy related Problems

- **Global Climate Change — risk is higher than previously thought**
- **Peak Oil Production & Demand Outstripping Supply**
- **Renewable energy plentiful- but limited by intermittent supply**

# Vehicle & Electric Grid

- **Smart interaction between vehicle fleet, grid and intermittent renewable**
- **Large, low-cost storage for renewables**
- **Vehicle-to-Grid (V2G) power as bridging technology**

# **How Can Electric Vehicles Benefit the Grid ?**

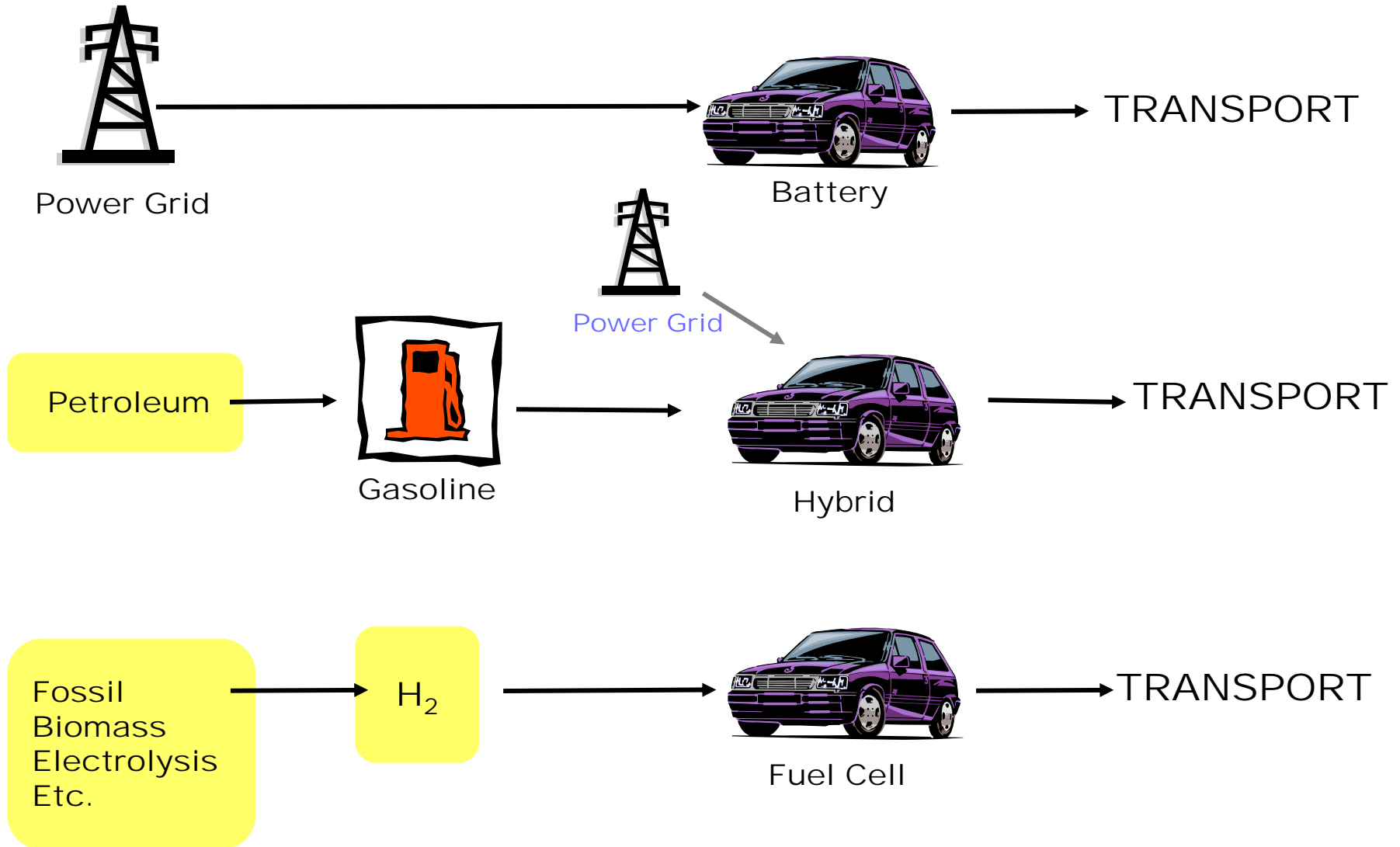
- **P of Vehicle Fleet > P of Electric Power System**
- **Grid-connected vehicle can provide:**
  - **1) Profitable Grid Management- Ancillary Serv.**
  - **2) Storage and back-up for renewables (e.g. wind power)**

# VEHICLE TYPES

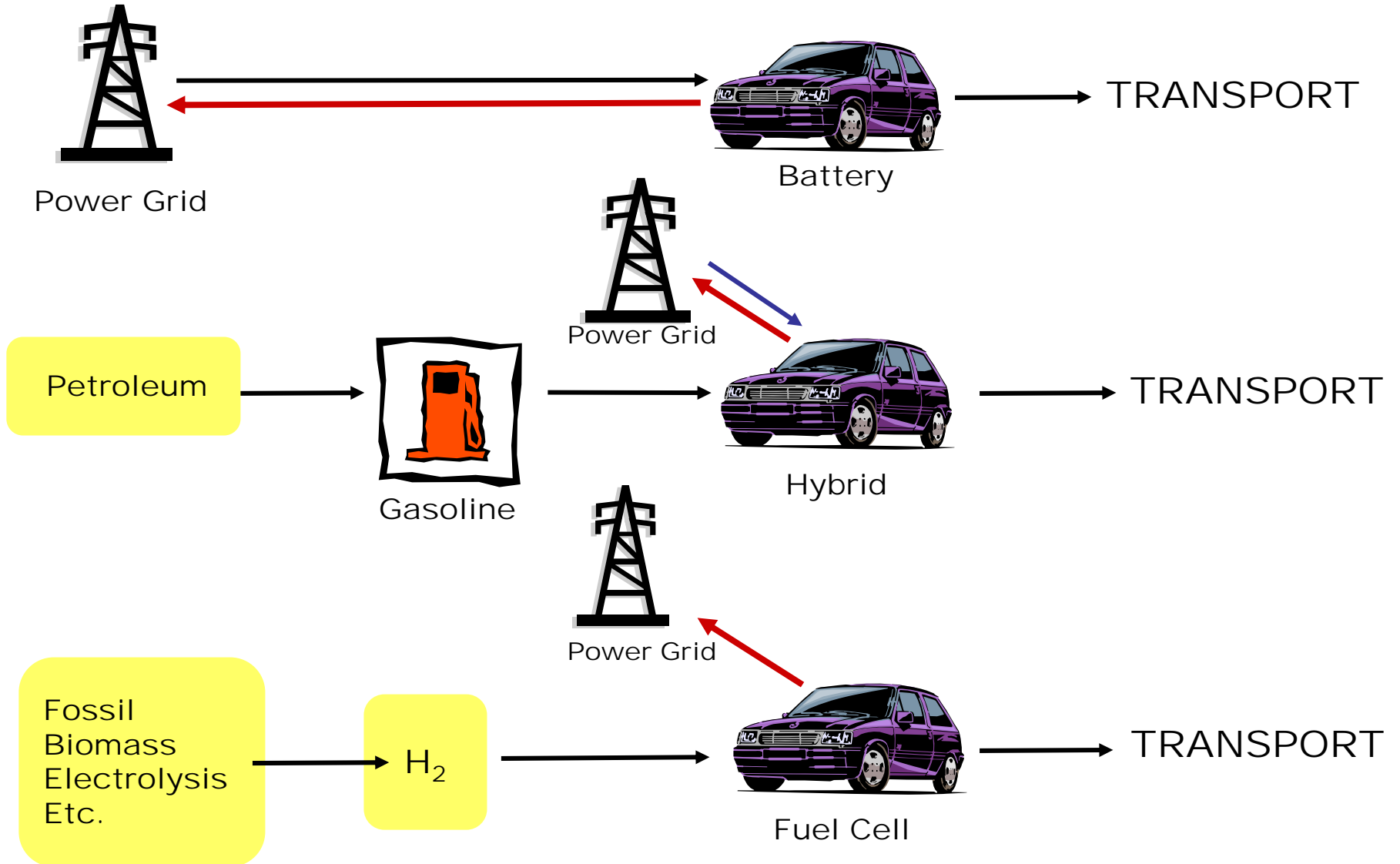
**Electric-drive Vehicles (EDV) means on-board power electronics producing AC power**

- **Battery: Full function & City Car**
- **Fuel Cell: On-board H<sub>2</sub> & stat. reformer**
- **Hybrid: ICE + battery**

# CURRENT EXPECTATIONS



# OUR PROPOSAL - V2G Power



# US POWER GRID vs VEHICLE FLEET

	<b>Power System</b>	<b>Vehicle Fleet</b>
<b>Units</b>	<b>9,500</b>	<b>200 mil</b>
<b>Ave. unit power (kW)</b>	<b>64,000</b>	<b>111**</b>
<b>System power (GW)</b>	<b>602*</b>	<b>22,200**</b>
<b>In-use factor</b>	<b>57%</b>	<b>~4%</b>
<b>Capital cost (per kW)</b>	<b>\$1,000+</b>	<b>\$60***</b>
<b>Electricity Cost (\$/kWh)</b>	<b>0.02-0.10 Ave</b> <b>0.05-0.80 peak</b>	<b>n/a</b>

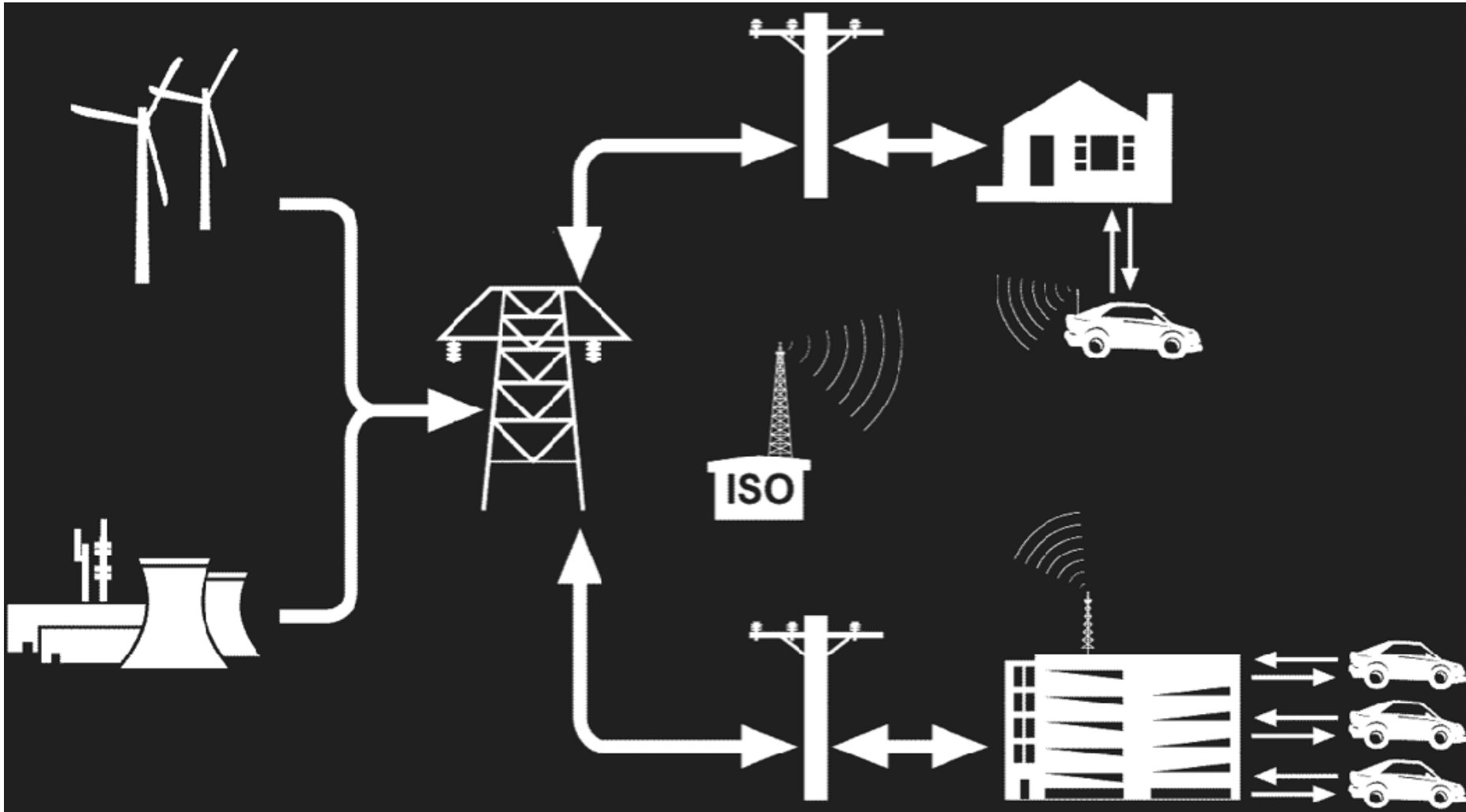
**\* Utility only    \*\* Mechanical    \*\*\* Drive train**

# US POWER GRID vs EDV FLEET

	<b>Power System</b>	<b>Vehicle Fleet</b>	<b>25% EDV</b>
<b>Units</b>	9,500	200 mil	50 mil
<b>Avg. unit power (kW)</b>	64,000	111**	15 ***
<b>System power (GW)</b>	602*	22,200**	750
<b>In-use factor</b>	57%	~4%	4%+
<b>Capital Cost (per kW)</b>	\$1,000+	\$60	\$10-200
<b>Electricity Cost (\$/kWh)</b>	0.02-0.10 ave 0.05-0.80 peak		0.10-0.50

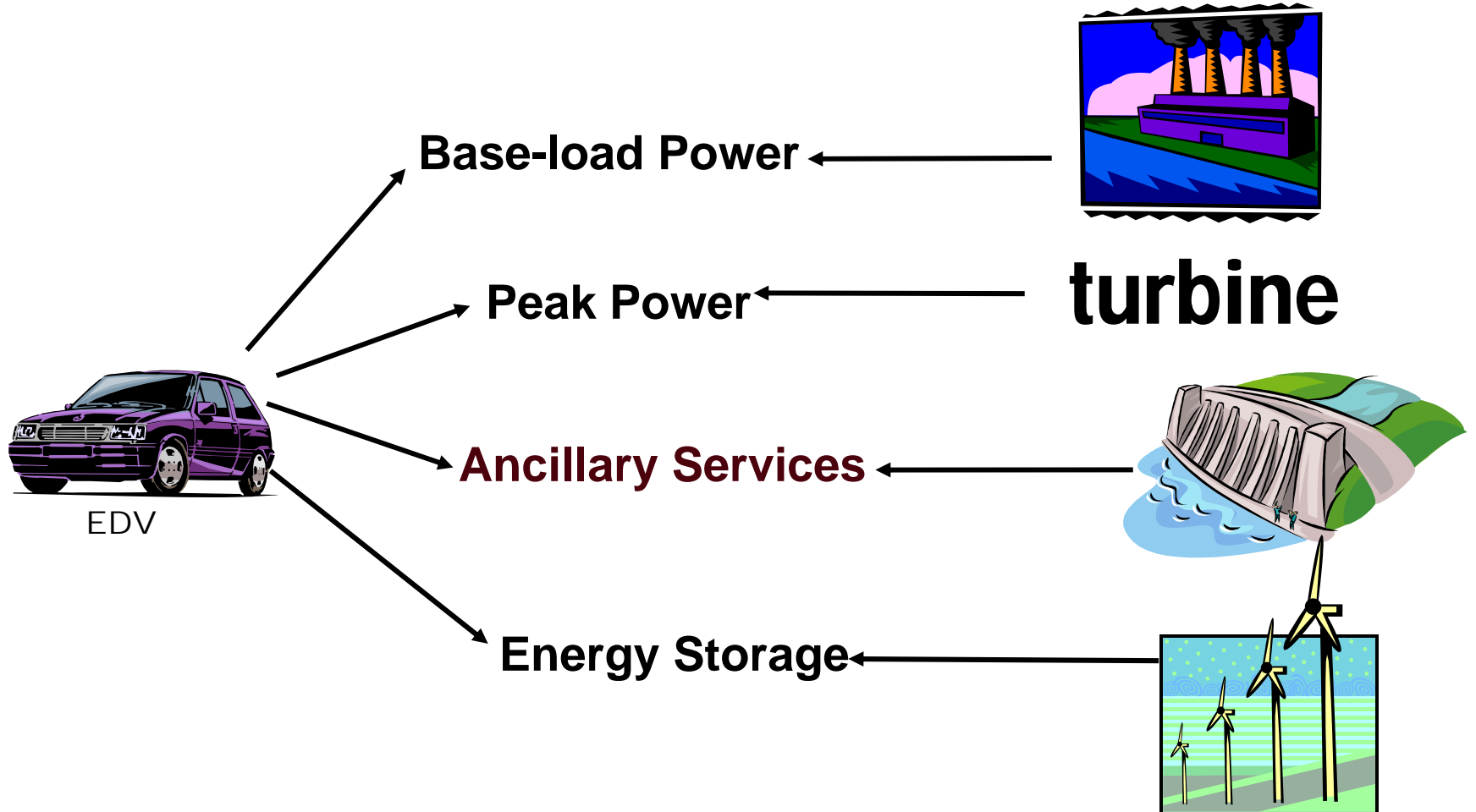
\*\* Utility generators    \*\* Mechanical    \*\*\* Limited P line of home

# Vehicle to Grid



**Arrows indicate direction of power flow**

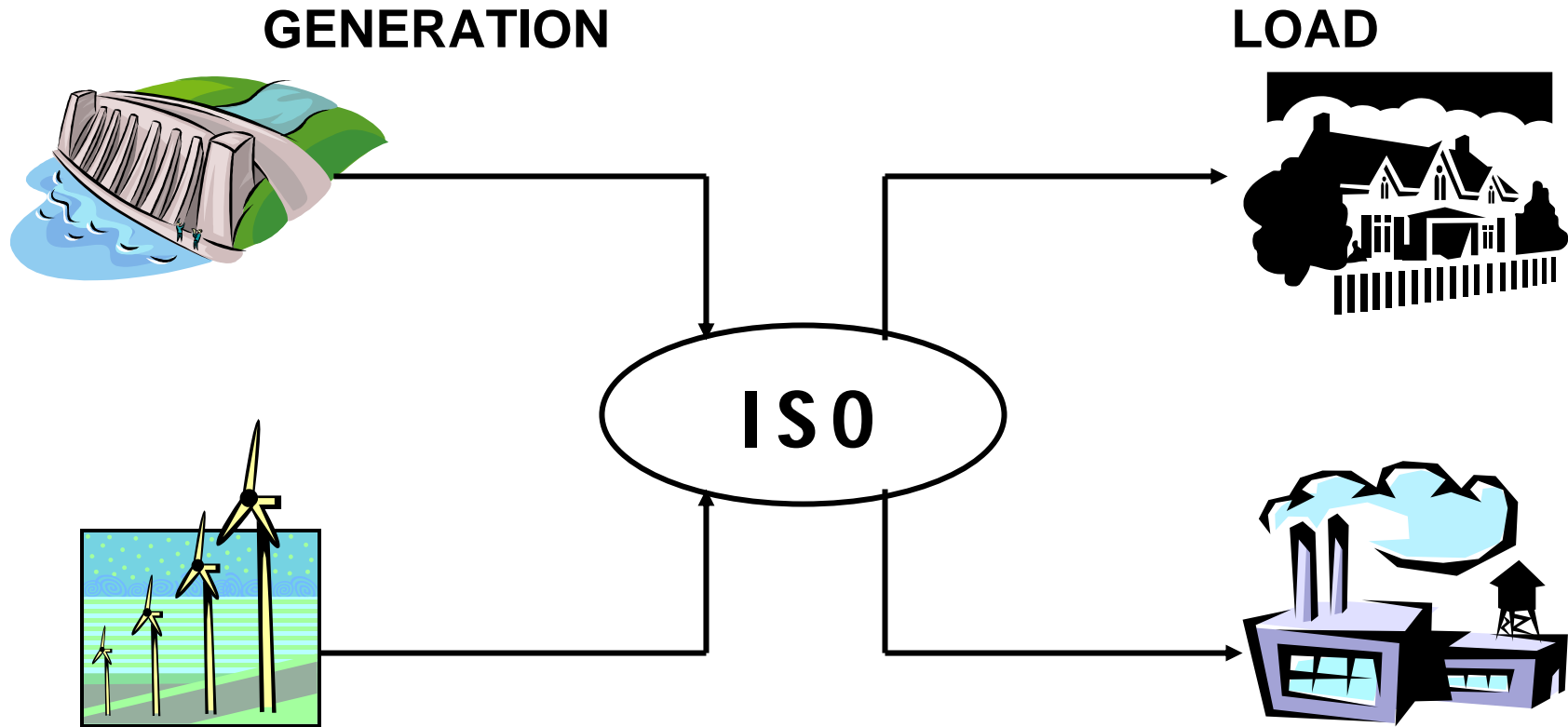
# USES FOR V2G POWER



# **V2G Power for Grid Management - Ancillary Services**

- **Ancillary Services (AS)**
- **Regulation Services**
- **Advantages of V2G for Regulation**
  
- **Utility EDV Fleets for Regulation Services**
- **Cost and Revenue Calculations**
- **Sample results of 2 fleet cases**

# Ancillary Services



- **Grid Management- Maintain grid reliability**
- **Balance Supply and Demand**
- **Support transmission of electric power**
- **A/S requirements 5-10% of the system load**

# Ancillary Services

- **Regulation:** On-line generation synchronized to the grid to keep frequency and voltage steady. Energy is increased/decreased instantly (~ 2-3 min) via automatic generation control (AGC)
- **Spinning Reserves:** Additional generating capacity synchronized with system to respond ~10 min in case of failures.
- **Payments consist of:**  
Capacity price (\$/MW-h) + Energy price (\$/MWh)

# Advantages of V2G for A/S

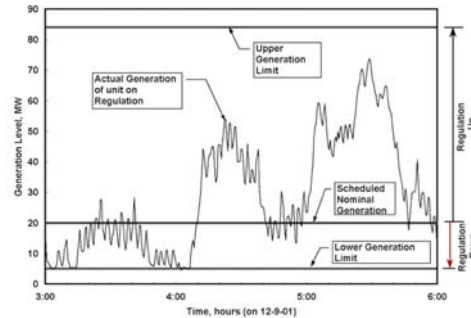
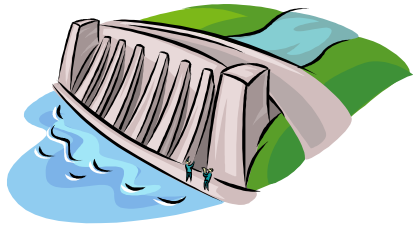
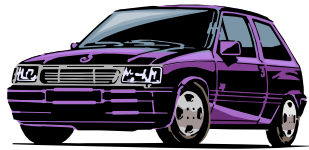
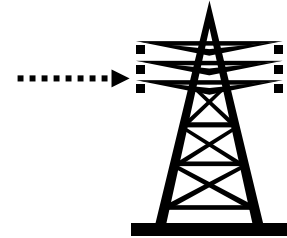
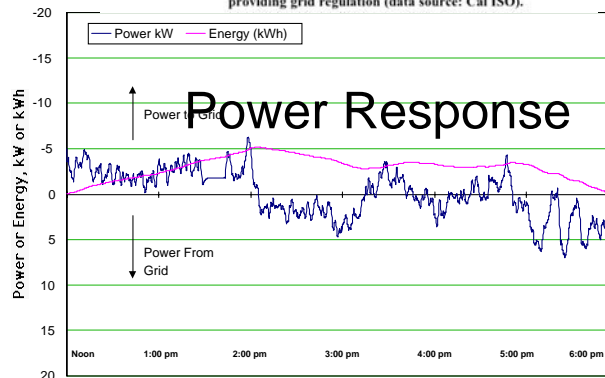


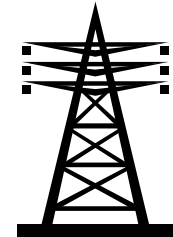
Figure 4. Example power generation profile of a hydro plant providing grid regulation (data source: Cal ISO).



EDV



POWER GRID



Source: Brooks 2001, 2002.

- Lower capital costs of generation and storage
- Rapid response in energy output
- Smaller maintenance costs

# Utility EDV Fleets for Regulation

## UTILITY EDV FLEETS

- **Utility EDV fleets already exist (battery EDV)**
- **Have a predictable schedule**
- **Utilities are familiar with A/S**

## REGULATION and SPINNING RESERVES

- **High value energy markets**
- **Compatible with battery EDVs**

# COST and REVENUE

$$r_{Reg} = (p_{cont} \bullet P \bullet t_{plug}) + (p_{el} \bullet P \bullet t_{plug} \bullet R_{d-c})$$

$$c_{Reg} = (c_{en} \bullet P \bullet t_{plug} \bullet R_{d-c}) + c_{ac}$$

$p_{cont}$	contract price for regulation (\$/kW-h)
$P$	power capacity (kW)
$t_{plug}$	availability of vehicles as fraction of day
$R_{d-c}$	energy dispatched as proportion of contracted power
$p_{el}$	market selling price of electricity (\$/kWh)
$c_{en}$	cost to produce energy (\$/kWh)
$c_{ac}$	annualized capital cost for V2G (\$)

# ENERGY COST

$$c_{en} = \frac{c_{el}}{\eta_{GBG}} + c_d \quad c_d = \frac{c_{bat}}{E_{LT}} = \frac{(E_s \cdot c_b) + (c_l \cdot t_l)}{L_C \cdot E_s \cdot DoD}$$

$E_s$  – energy stored on-board (kWh)

$c_b$  – cost of battery replacement (\$/kWh)

$c_l$  – cost of labor (\$/h)

$t_l$  – labor for battery replacement (h)

$DoD$  – depth of discharge allowed

$L_C$  – battery life in cycles

$\eta_{GBG}$  — efficiency grid-battery-grid

# Two Fleet Cases

**A. New York Station Cars —  
100 Th!nk City EV**



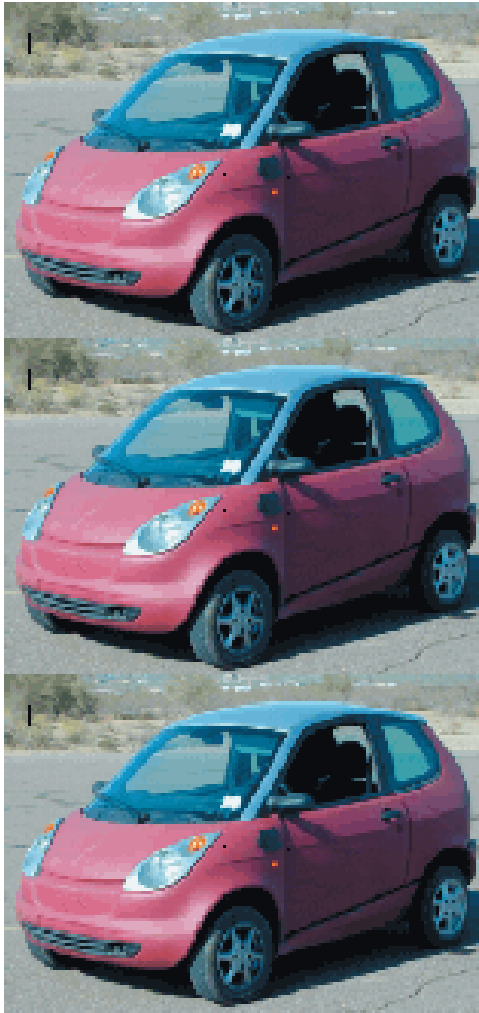
**B. CA Utility Fleet — 252  
Toyota RAV4 EV**



# Fleet Case A

## New York Station Cars

100



- For regulation services
- Upgrade cost for V2G included
- $P_{\text{line}} = 6.2 \text{ kW}$
- $t_{\text{plug}} = 23 \text{ h}$
- $c_{\text{el}} = 0.05 \text{ \$/kWh}, c_{\text{en}} = 0.16 \text{ \$/kWh}$
- NY ISO Regulation Capacity price  
 $p_{\text{contr}} = 27.5 \text{ \$/MW-h (2003)}$

# Calculated Profits

## Case A



**YEAR 2003**

<b>FLEET POWER kW</b>	<b>Revenue</b>	<b>Cost</b>	<b>Net Profit</b>
<b>620</b>	<b>\$ 311,700</b>	<b>\$ 99,500</b>	<b>\$ 212,200</b>

252

# Fleet Case B

## Utility EDV Fleet



- For regulation services
- Upgrade costs for V2G included
- $P_{\text{line}} = 15 \text{ kW}$
- $t_{\text{plug}} = 17 \text{ h}$
- $c_{\text{el}} = 0.05 \text{ \$/kWh}, c_{\text{en}} = 0.15 \text{ \$/kWh}$
- CAISO Regulation Capacity price (2003)
  - $\text{Reg}_{\text{up}} \quad p_{\text{contr}} = 19.5 \text{ \$/MW-h}$
  - $\text{Reg}_{\text{down}} \quad p_{\text{contr}} = 20.3 \text{ \$/MW-h}$

# Calculated Profits

## Case B



**YEAR 2003**

<b>FLEET POWER kW</b>	<b>Revenue</b>	<b>Cost</b>	<b>Net Profit</b>
<b>@15 kW 3,780</b>	<b>\$1,039,000</b>	<b>\$380,000</b>	<b>\$659,000</b>

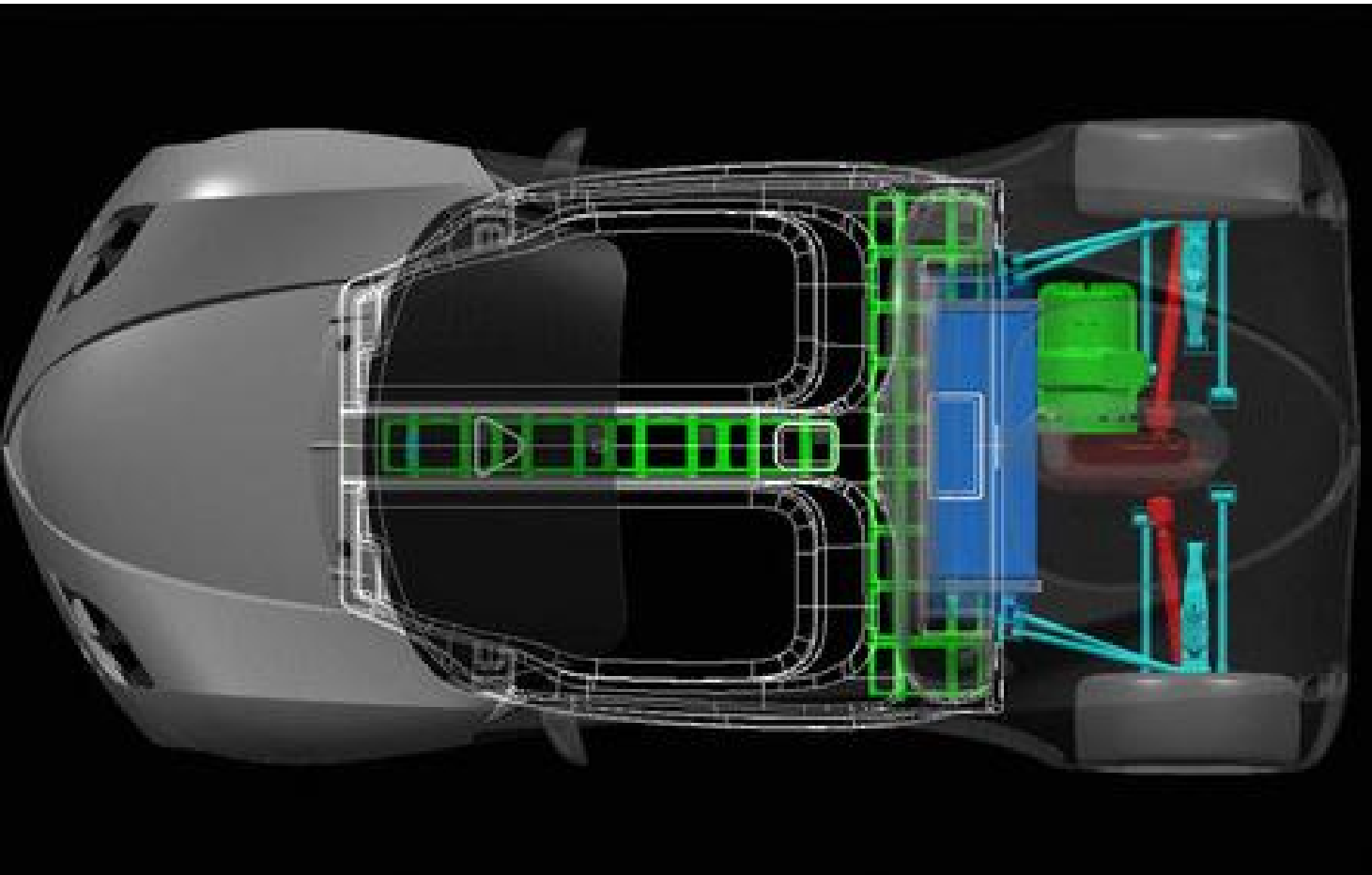
# Summary

- **2 fleet case analyses in different markets show significant economic potential for V2G providing A/S**
  - **Fleet of 100 small EDVs in NY**  
**Revenue of \$200,000**
  - **Fleet of 250 EDVs in CA**  
**Revenue of \$660,000**
- **Important parameters:**
  - **market value of A/S**
  - **kW capacity of vehicles and electrical connections**
  - **kWh capacity of vehicle battery**

# Conclusions (1)

- **EDVs are promising sources of grid power**
- **V2G has high market value for regulation services and spinning reserves**
- **Utility fleets can be early adopters of V2G technology**

# Venturi Fetish



**58 kWh Li-ion**  
**180 kW**  
**400 km range**

**standard:**  
**WiMax 802.16**  
**2 Intel chips**  
**Oracle 10G**  
**iPod**  
**V2G**

**0-100 km/h in 4.5 sec, max 170 km/h**

19 Sep 05 press release:

<http://www.internetnews.com/ent-news/article.php/3549956>





# EV Toyota Scion - conversion by AC Propulsion

## Scion xB

Compact Utility Vehicle

Spacious, comfortable,  
unique, sporty, versatile



## Scion xA

Compact Sport Wagon

Fun, useful, nimble, roomy,  
efficient

# EV Toyota Scion by AC Propulsion



	Base	Premium
AC Induction Motor	75 kW	130 kW
Vehicle Weight	2570 lb	2850 lb
Range	80-110 mi	150-210 mi
Acceleration 0-60	< 9 sec	< 7 sec
Top Speed	82 mph	90 mph
Battery Type	Li Ion	
Battery capacity	20 kWh	35 kWh
Charging	Plug-in-anywhere Fast charge in 2 hrs V2G capable	
Features	A/C, full power	

**“We plan to manufacture safety-certified electric vehicle conversions and sell them to retail and fleet customers. The conversions will be based on the Scion xA and xB, the new sport compact vehicles built by Toyota...”**

**“We plan two models, a base model, and a premium with a larger battery. The base model will outperform the RAV4 EV and is expected to sell for about the same price.”**

## Scion xB

Compact Utility Vehicle  
Spacious, comfortable,  
unique, sporty, versatile



## Scion xA

Compact Sport Wagon  
Fun, useful, nimble, roomy,  
efficient

# Effect of EVs with V2G on Grid Infrastructure Requirements

- **50% of cars as EVs increase electric load ?**  
100 Million cars  
x 15,000 Miles per year / 4.8 Miles per kWh  
= 312 Billion kWh per year at off-peak times  
= **7% of 2020 total national load**
- **With V2G, these EVs also provide a huge power resource:**  
100 M cars \* 15 kW \* 0.5 avail. = 750 GW of DG  
> **70% of 2020 national electric power capacity!**

**Conclusion: Even 50% of cars as EV, IF they have V2G, probably REDUCE grid infrastructure requirements**

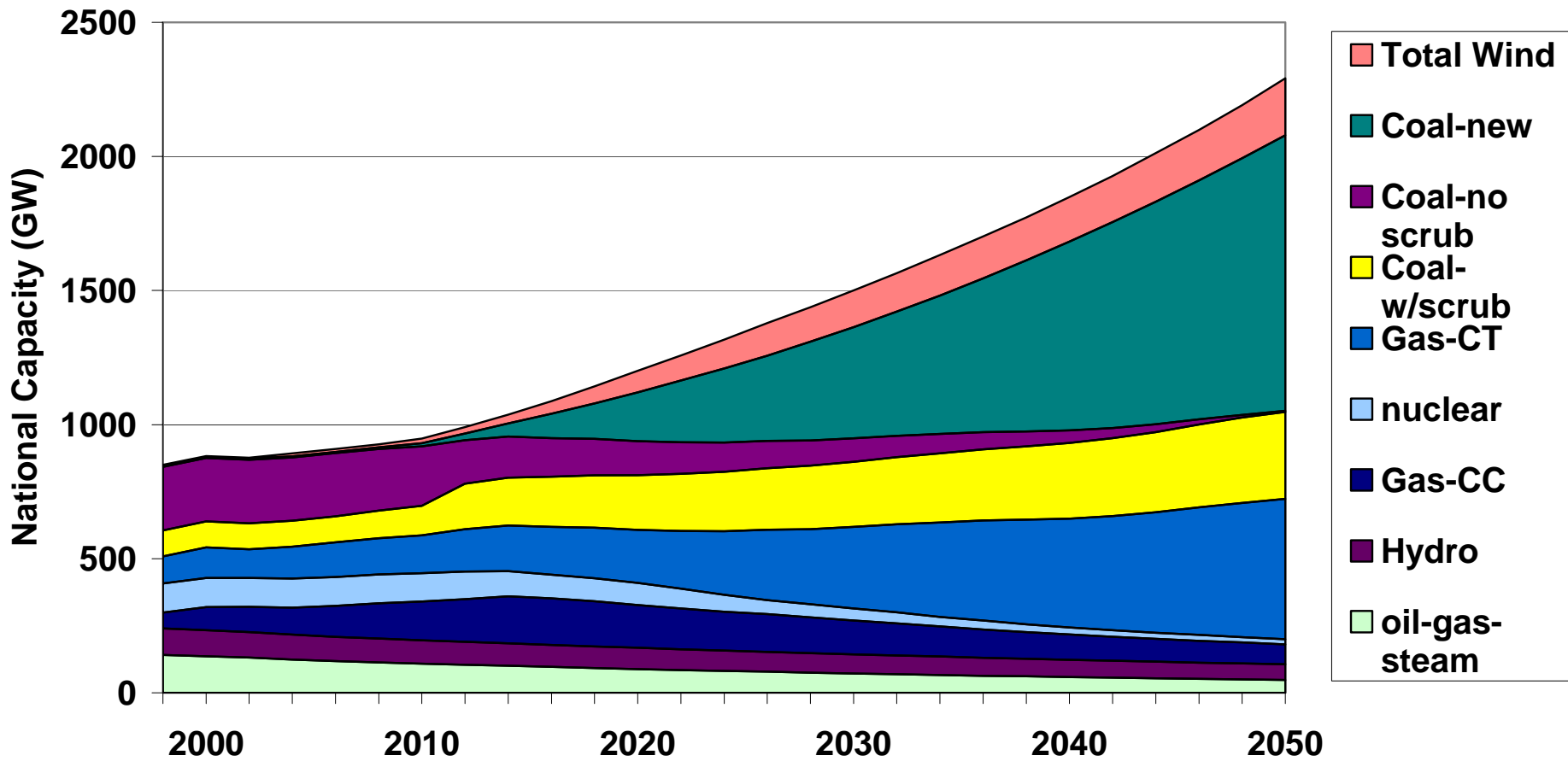
(Using “back of the envelope” method from W. Short, NREL, 2005)

# **Electric Vehicles - Storage for Wind**

- **Use of Electric-drive vehicle could increase the wind resource dramatically**
- **“Business as usual” model — 200 GW from wind**
- **With electric vehicles — 700 GW from wind**

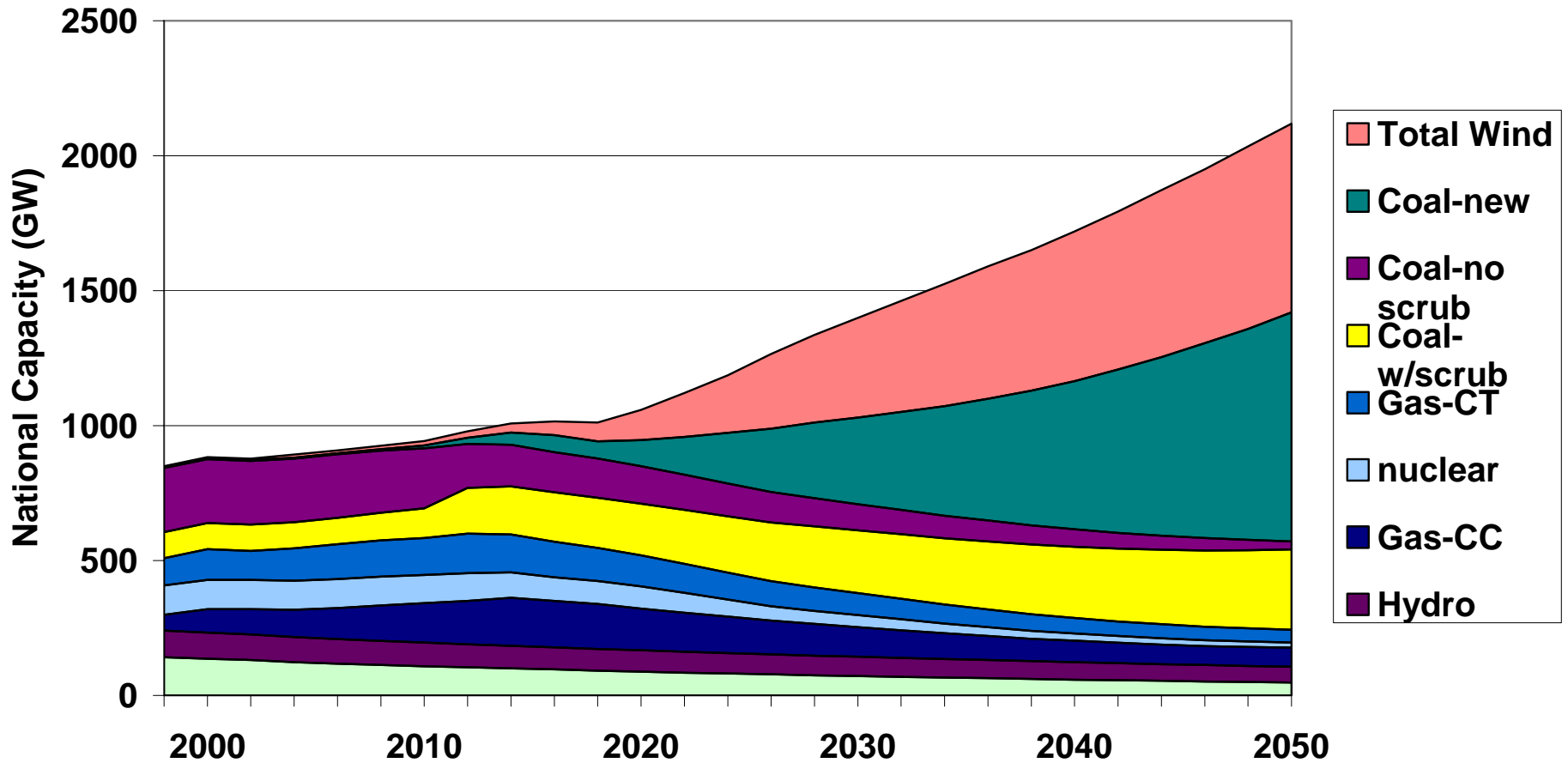
# Base Case Electricity Capacity

EIA Forecast Model, No new policy



Source: W. Short Presentation, NREL, preliminary results

# Results of NREL's WinDS Model with 50% PHEVs by 2020



Source: W. Short Presentation, NREL, preliminary results

# CONCLUSIONS

- **V2G provides a link between the electric power system and vehicle fleets.**
- **V2G introduces the dual use of vehicles — for transportation and power generation.**
- **V2G has high market value for A/S (grid management) and can provide storage for renewable power sources.**
- **Benefits — clean transportation (no CO<sub>2</sub>) and clean source of electric power.**

# **Acknowledgments**

**Funded in part by:**

**Kirsch Foundation and  
Conectiv Power Delivery**

**More information:**

**[www.udel.edu/V2G](http://www.udel.edu/V2G)**