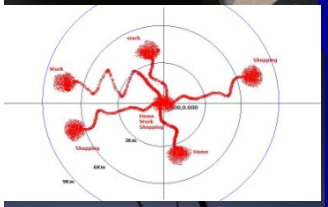
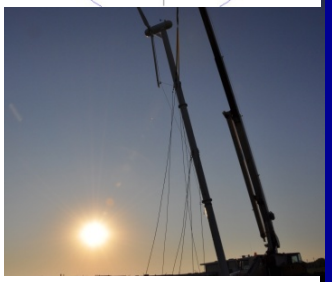
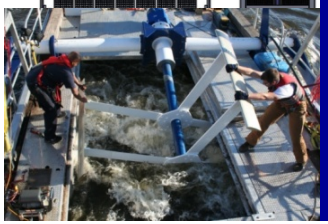




Repurposing PEV batteries

Supporting renewables meet the drivers

Dr. Eric Bibeau

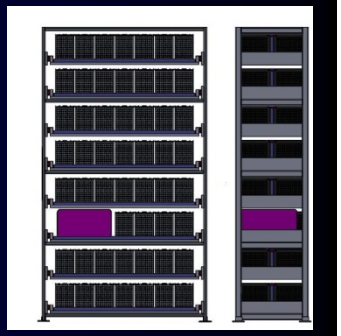
Mechanical & Manufacturing Engineering Dept

NSERC/Manitoba Hydro Alternative Energy Chair

PHEV'09 Plug-In Hybrid and Electric Vehicles September 28 to 30, 2009 – Montreal

Véhicules électriques et hybrides rechargeables 28 au 30 septembre, 2009 – Montréal

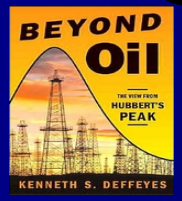
Repurposing Outline



- **Why: repurposing background**
  - Energy drivers: electric mobility
- **What: repurposing issues**
  - Utility focus
- **How: repurposing project**
  - Planning stage

WHY: Energy Drivers

- Peak oil



- Environmental emissions

- GHG leading to global warming

- Sustainability

- Energy security

- Costs

Paths to address energy drivers in transportation

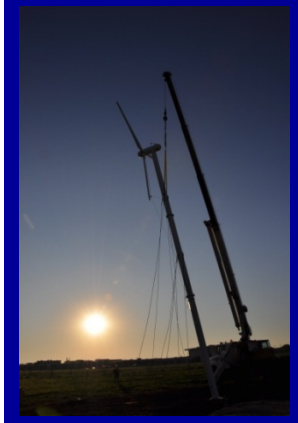
- **Substitution approach**
  - Tailpipe emission reductions at the expense of energy drivers
    - Hydrogen from electrolysis

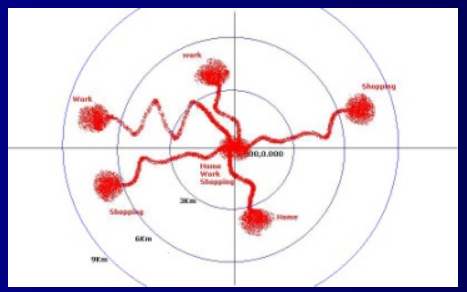
Paths to address energy drivers in transportation

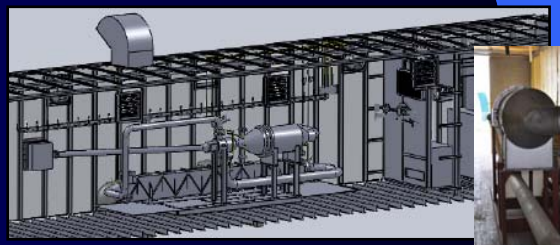
- **Impervious approach**
  - Fossil fuel reductions by relinquishing significant potential
    - Biofuels from residual biomass feedstocks

Paths to address energy drivers in transportation

- **Sensible approach**
  - Address energy drivers together
    - Use electric mobility
      - increase the **RER**
      - apply **RED** levers







Using Electric Mobility to increase RER

Addressing the energy problem, not just the vehicle

$$RE = 1.857 \ \ EJ \qquad FF = 9.469 \ \ EJ$$

$$RER = \frac{RE}{PE} = \frac{RE}{FF + RE}$$

$$\frac{1.857 \ \ EJ}{(9.469 + 1.857) \ \ EJ} = 16.4\%$$

Electric Mobility
Increase RER using RED levers

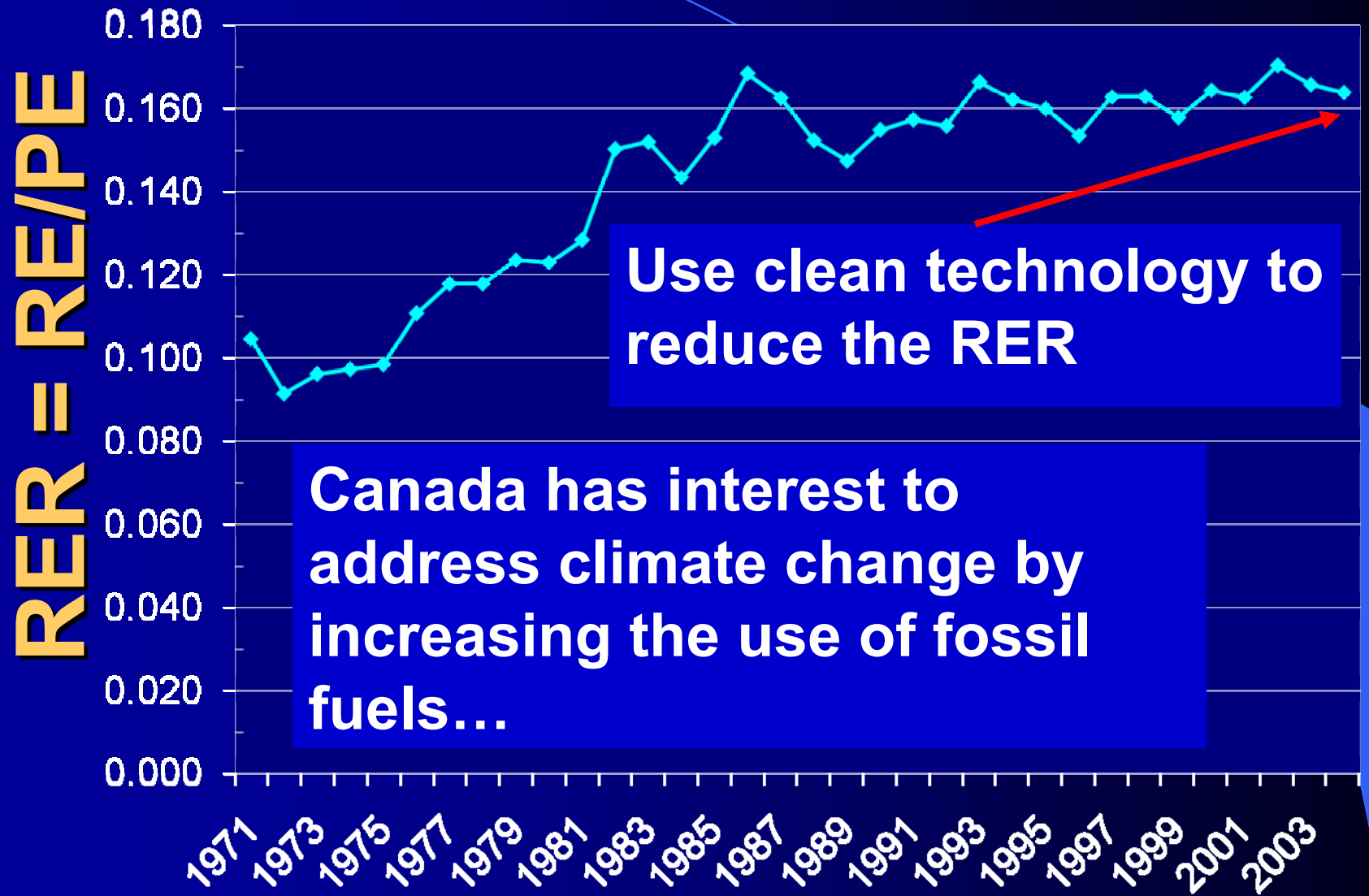
$$\frac{1.857 \ \ EJ}{(9.469+1.857) \ \ EJ} = 16.4\%$$

R – Add Renewable energy

E – Increase energy Efficiency

D – Lower energy Demand

Canada's RER Performance



RER as optimization parameter

- **Sensible approach to address energy drivers**
  - Focus on optimization of energy inputs (RER) rather than system outputs (GHG)
- **Focus on system outputs: problematic**
  - A new battery electric vehicle added in Manitoba needs to displace at least 0.71 kg/kWh, or else total world GHG's increases
  - System boundary

Power Export GHG Displacements	Assumed MH Export Profile (%)	Current Emission Factor (kg CO_2/kWhr)
North Dakota	10	1.02
Minnesota	80	0.69
Saskatchewan	5	0.83
Ontario	5	0.24
	Total	0.71

Properties of RED Levers

Renewables, Efficiency, Demand

- **Independent**
  - Cannot claim any relationship among levers
    - e.g.: wind mill cannot go directly to an electrolyser
- **Relative**
  - Change occurs on a relative, not absolute basis
    - e.g.: introduction of electric mobility independent of electrical energy mix

- **Equal in value**
  - RE = Efficiency = Demand

How to loose weight?

RBR

- Eat better (R)

- Exercise (E)

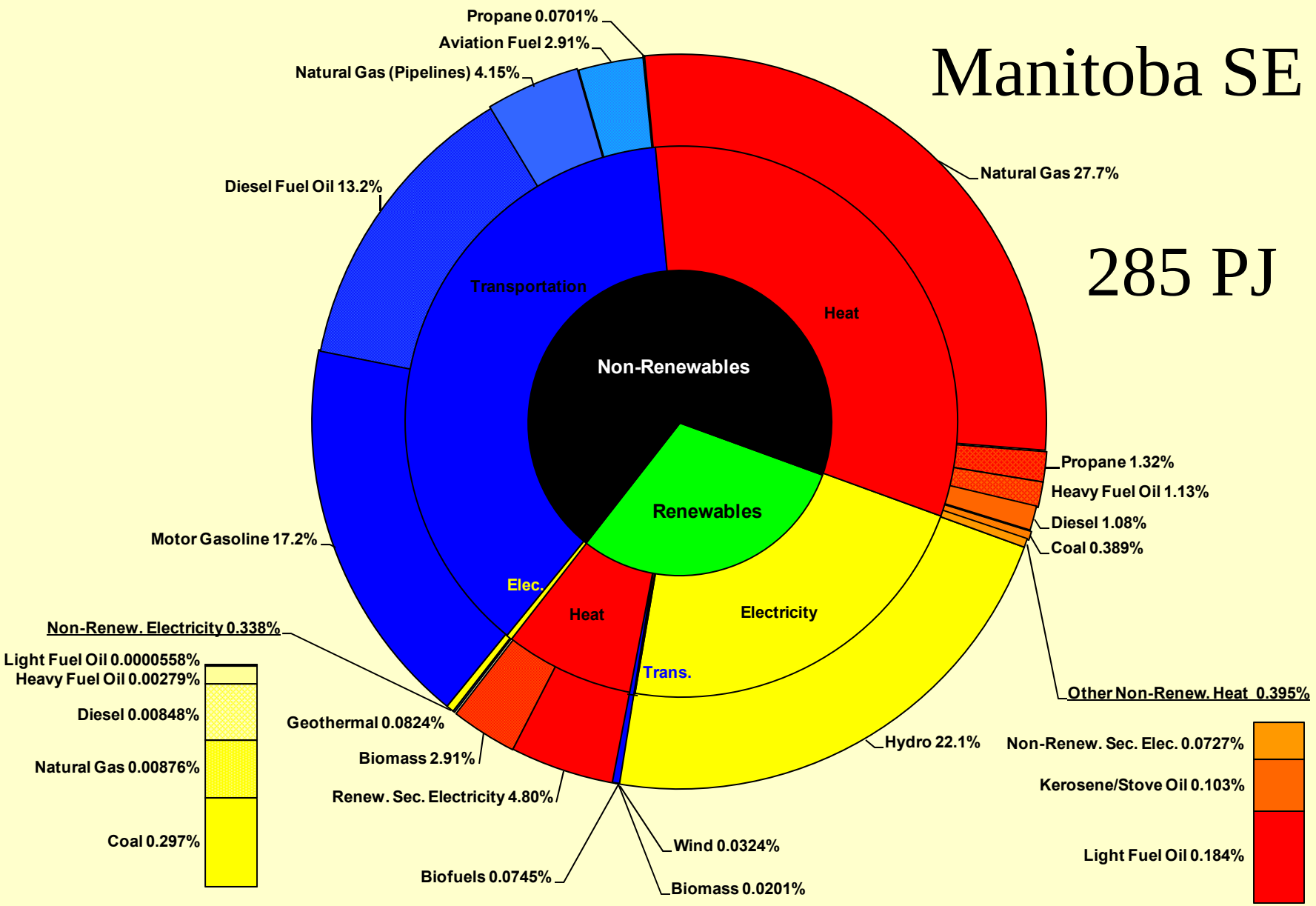
- Eat less (D)

How to evaluate?

…as a result of increased obesity we decided to reduce humane waste to pre 1990 levels

Manitoba SE

285 PJ



Manitoba

$$RER = \frac{90{,}000\ \ TJ}{(90{,}000 + 200{,}000)\ \ TJ} = 31\%$$

Manitoba Passenger Transportation Motor Gasoline Consumption (TJ)		% of MB's Total PE Consumption
Small Car	7,800	3%
Large Car	9,000	3%
Passenger Light Truck	14,900	5%
Other	200	
Total	**31,900 TJ**	**11%**

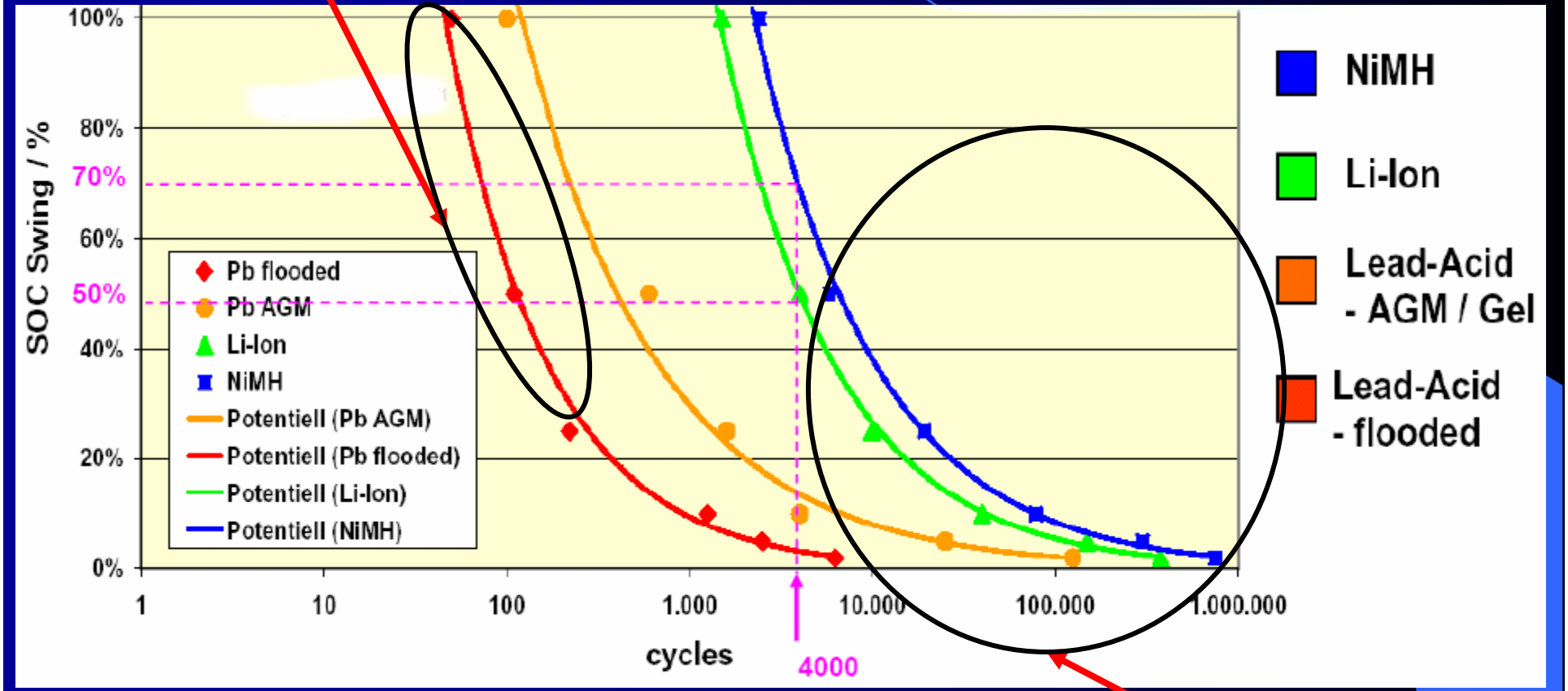
Electric Mobility
3 levers to increase RER

- **E – Increase Efficiency**
  - Change ICE to PEV (reduce PE)
- **R – Add Renewables**
  - all new PEV loads (increase RE)
- **D – Lower Demand**
  - Reduce vehicle weight: PowerSmart (reduce PE)

Strategic Intelligence

What: Batteries used in Utilities

Power backup applications (trickle charge)

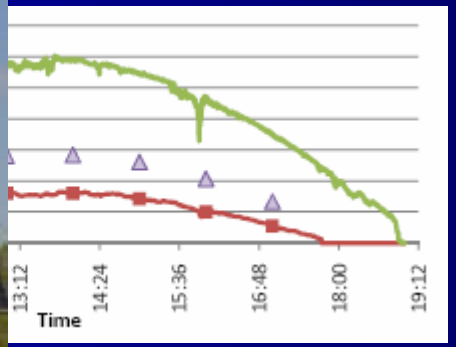


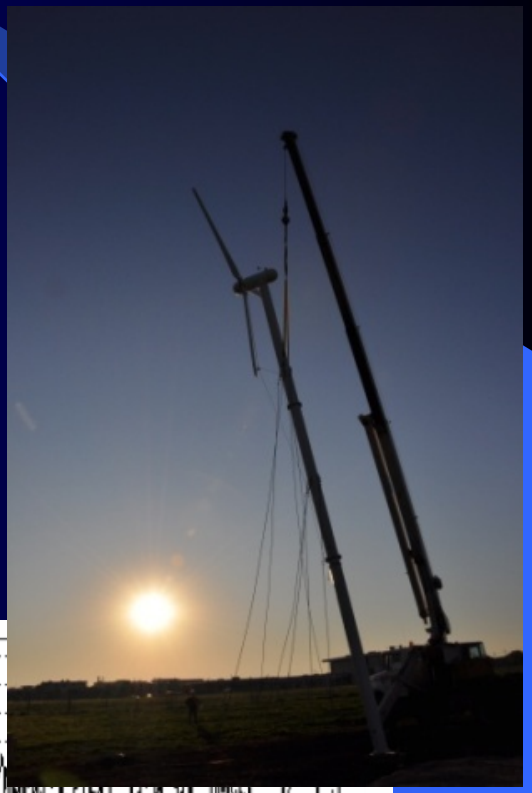
New applications using new and repurposed Li-ion

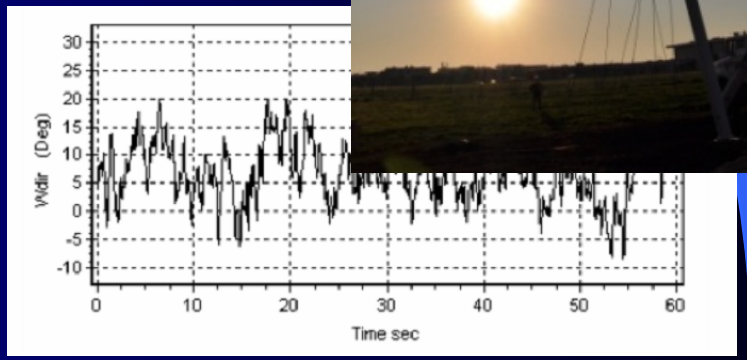
Adapted from : Christain Rosenkranz, EVS 20, Long Beach, CA, Nov 15-19, 2003

Repurposing batteries supporting renewables

- **Intermittent renewables and storage**
  - Wind Energy
  - Solar using Photovoltaic

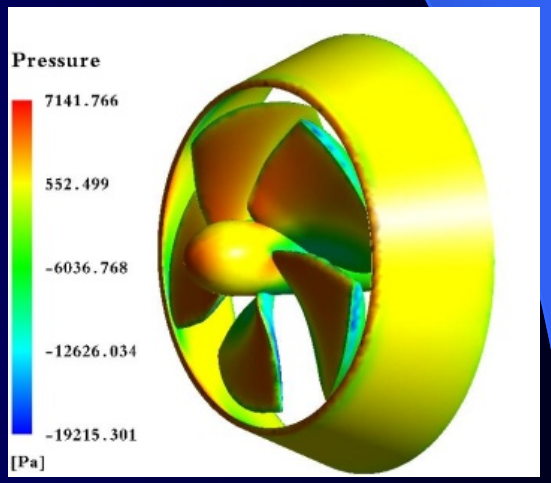






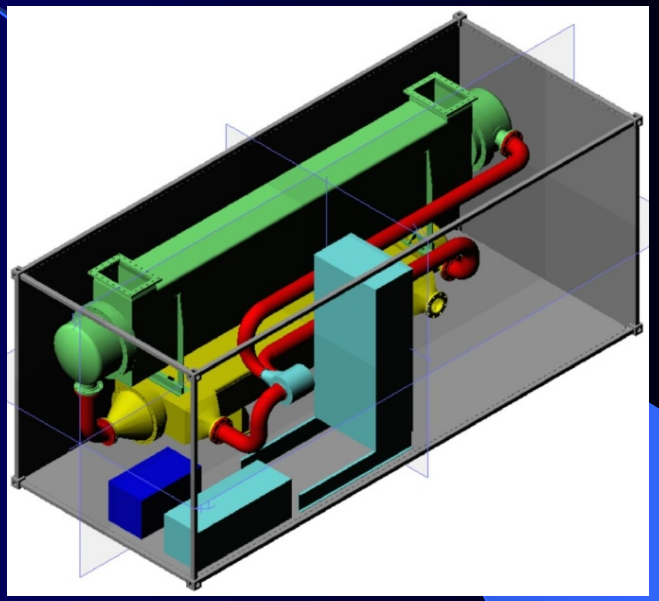
Repurposing batteries supporting renewables

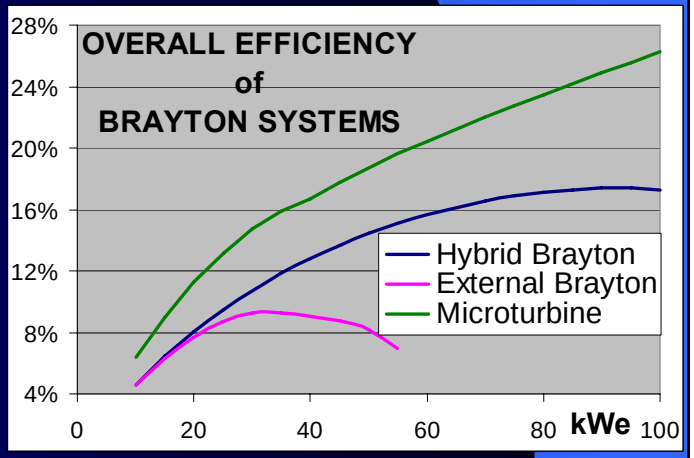
- **Marine Hydro and storage**
  - Follow community peak loads
  - Build less turbines in isolate communities
  - Address tide variations
  - Increase revenues: peak incentives



Repurposing batteries supporting renewables

- **Small-Scale Biomass CHP**
  - Provide heat, power, cooling
  - Increase RER of a community quickly
  - Storage allows to respond faster to load changes
    - Response of thermal conversion system slower than power changes





Electric Mobility Costs

- **Charge Cycle Costs**

$$\frac{Battery\ Capital\ Cost\ (\$/kWh)}{DOD\ \min\ (3200^{*},\ cycle\ life)}$$

Note: Assumed values	Now	Intermediate Future	Future
Pack Capital Costs	1000	800	600
DOD	0.5	0.6	0.75
Cycle Life	3000	4000	5000
Charge Cycle Costs	$0.67	$0.42	$0.25
Charge Cycle Costs/Power	11.1	6.9	4.2

*Approximate value and will be determined from AUTO21 study

Electric Mobility/Renewables Cost Ratio



Renewables	Wind	Biomass	Hydro
Capacity Factor	0.35	0.9	0.75
Cost per kW peak	$2,200	$3,800	$4,000
kWh/kWp/year	3,066	7,884	6,570
Year life span	25	30	50
$/kWh life span	$0.72	$0.48	$0.61
$/kWh per year	$0.029	$0.016	$0.012
$/PEV/year	$64.58	$36.15	$27.40
Cost ratio PEV owner/utility	**23.2**	**41.5**	**54.8**

*Battery at $1,000/kWh for 15 kWh power pack per PEV (all interest excluded)

Maximizing RER
Optimization of Cost/Benefit

Diminishing RER Returns

PEV	Infrastructure	Energy
Small battery pack	Access to level 1 charging	Hydro
	Access to level 2 charging	Biomass
		Wind
Large battery pack	Access to level 3 charging	Peaking Plant
	V2G, Battery swapping	New fossil

Repurposing should not add unnecessary infrastructure

Utilities: Repurpose or V2G

References	Vehicle to grid	Battery repurposing
Google	237,000	3
Engineering Village Index	2,985	0

	Vehicle to grid	Battery Repurpose
Different BMS/compatibility	no	yes
Testing/refurbish required	no	yes
Potential lower cost	no	yes
Costly infrastructure	yes	no
Waiting for access	no	yes
Favored by high charge cycle costs	no	yes
Favored by low charge cycle costs	yes	no
Safety issues	yes	no
Potential to increases RER	no	yes
Liability	yes	no

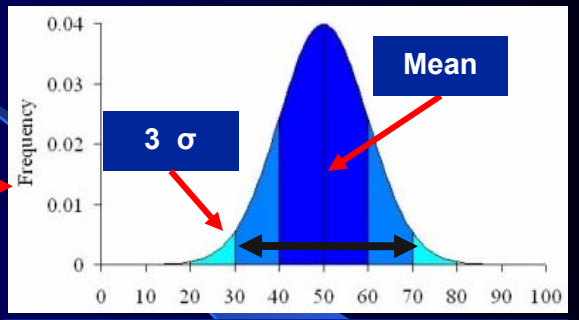
Utilities: Repurpose or V2G

Extra costs for V2G

$$f(x) = \frac{e^{-(x-\mu)^2/(2\sigma^2)}}{\sigma\sqrt{2\pi}}$$

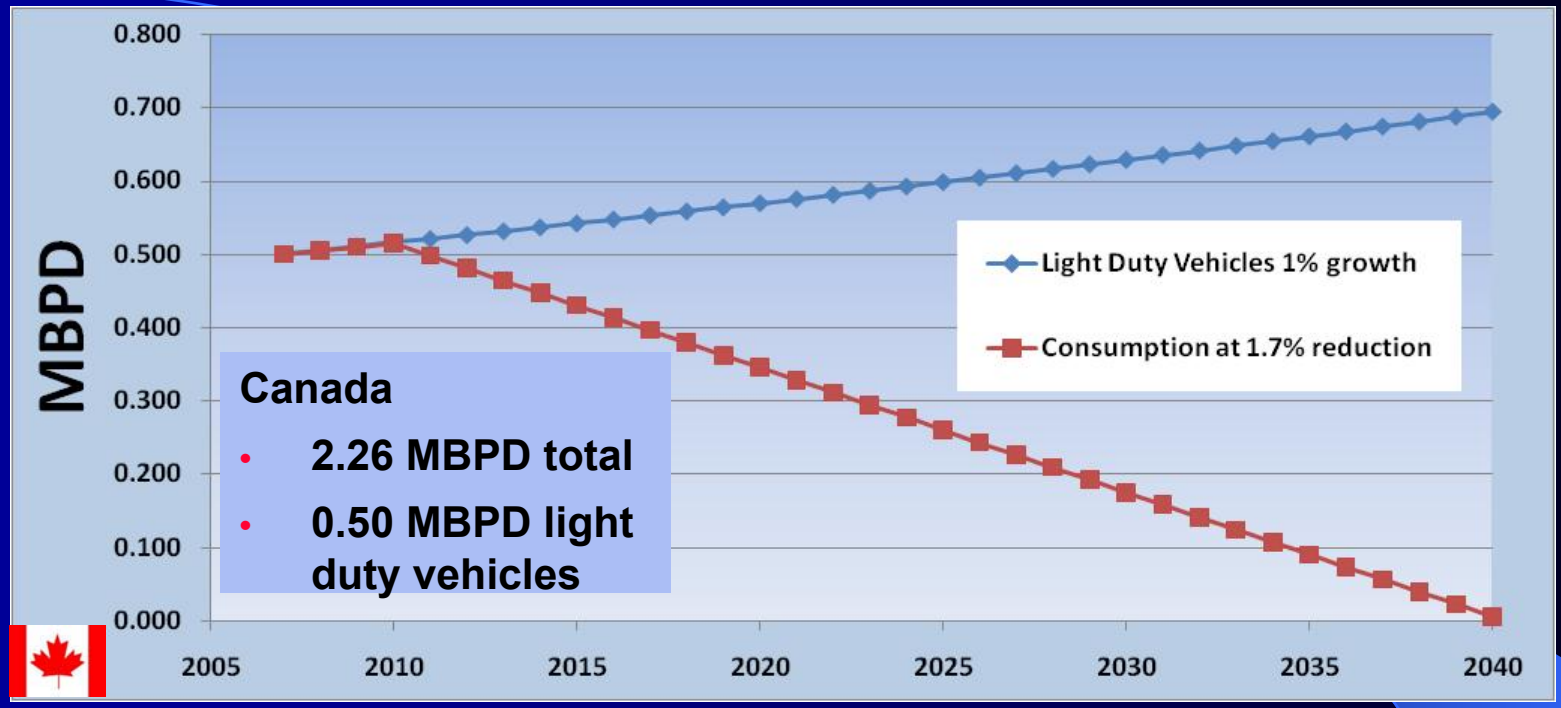
μ = mean
σ = standard deviation

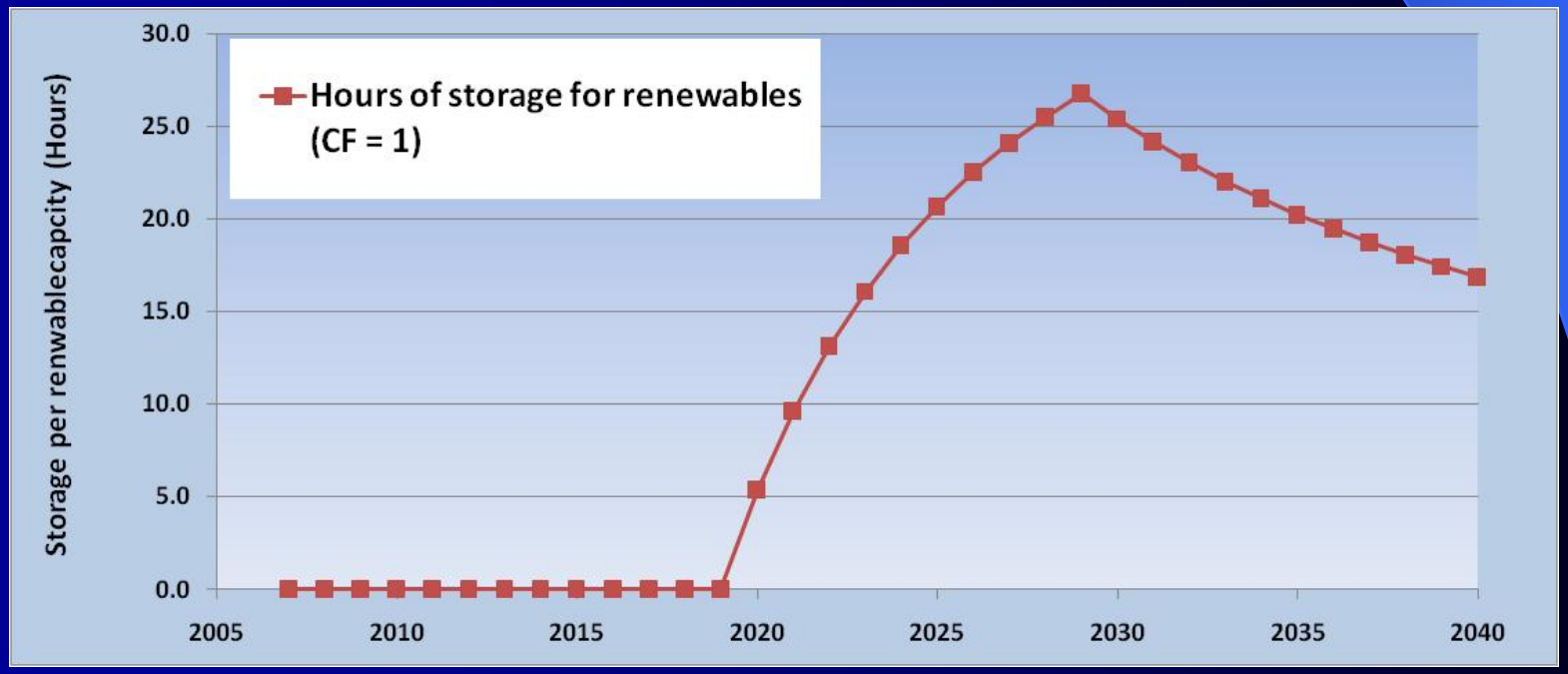
Normal distribution



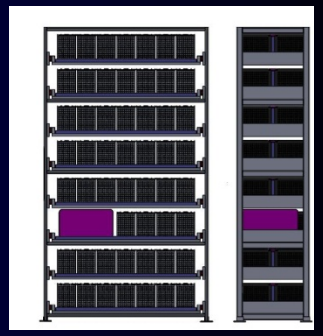
Charge Cycle Cost (c/kWhr)

Charge Cycle Cost before user profit		Utilities Impact	
Payment	Underpaid Probability	Liability	Extra Costs
Mean	50.0%	very high	none
1 standard deviation	16.0%	high	high
2 standard deviation	2.5%	medium	very high
3 standard deviation	0.2%	low	very high


MBPD
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
2005
2010
2015
2020
2025
2030
2035
2040
Light Duty Vehicles 1% growth
Consumption at 1.7% reduction
Canada
• 2.26 MBPD total
• 0.50 MBPD light duty vehicles


Storage per renwablecapcity (Hours)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2005
2010
2015
2020
2025
2030
2035
2040
Hours of storage for renewables (CF = 1)

How Repurposing Project Objectives



- **Secondary utility market for PEV batteries**
- **Test concept of repurposing PEV battery packs into stationary applications**
  - Optimal generation/storage to follow remote community load
  - Reduce fossil fuel used in peaking plants
  - Avoid feeder upgrade by addressing load congestions
  - More value for intermittent renewables
  - **Focus on storage applications for renewable energy generation**
  - **Modular design to integrate with new battery storage**

Repurpose Questions

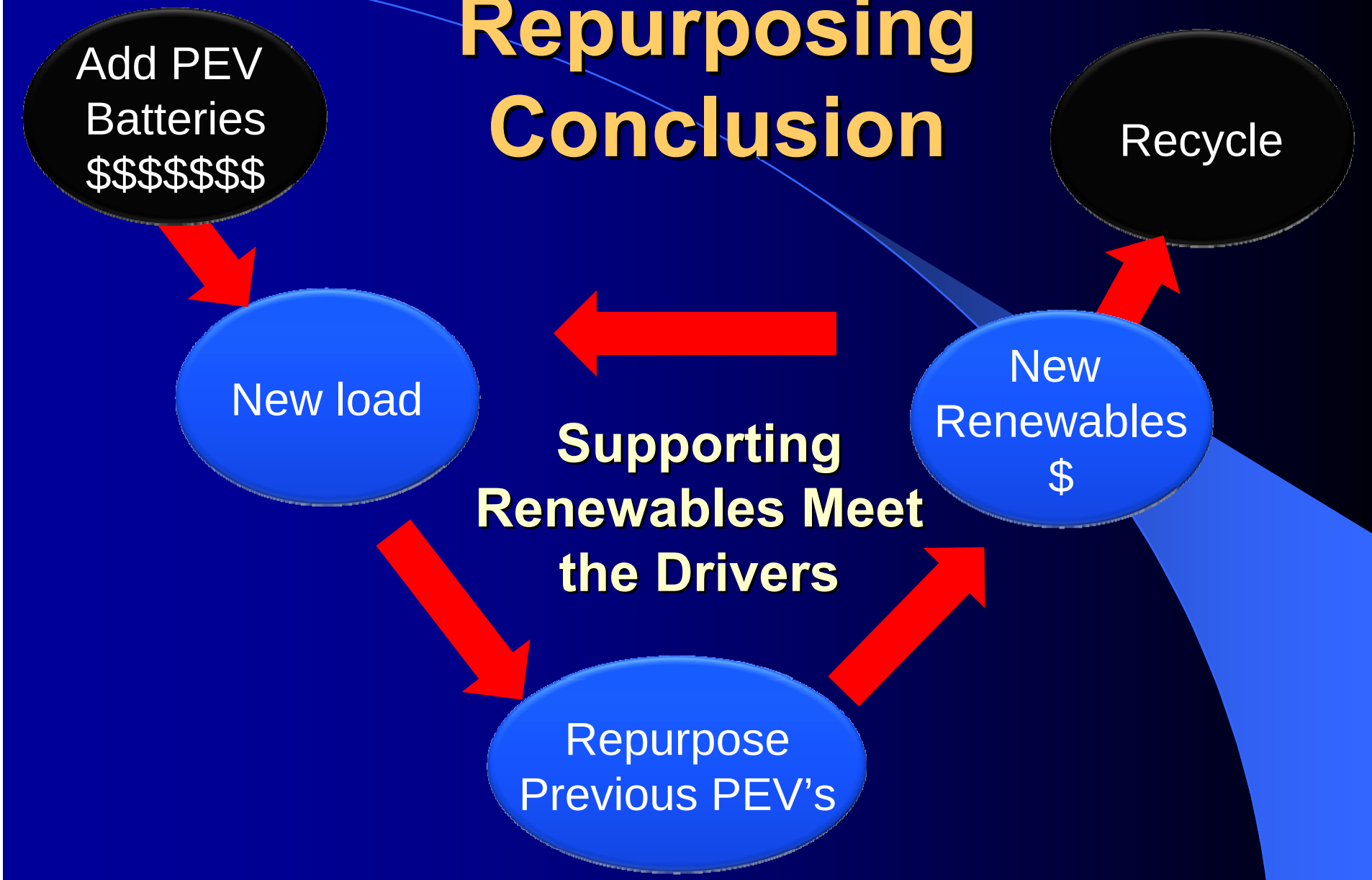
- Can it accelerate PEV deployment?
- Can it address safety issues with tinkering?
- Can it avoid V2G infrastructure cost?
- How can utilities justify repurposing?
- How to minimize conversion: mobile battery to stationary?
- What should DC bus voltage?
- What tests need to be done on used packs?
- What is best value proposition for utilities?
- What is best charging and discharging rates?
- Will OEM's develop packs that completely fail after end of vehicle life?

Repurposing Research Partners

As part of Utility-scale Li-ion Battery Storage Project with additional partners

- **Hydro One Networks**
- **Toronto Hydro-Electric System**
- **Verdant Power Canada**
- **Ryerson University**

Repurposing Conclusion



Applying strategic intelligence to increase the RER using electric mobility

Acknowledgement

- NSERC/Manitoba Hydro Chair in Alternative Energy

Presentations on alternative energy

- http://home.cc.umanitoba.ca/~bibeauel/