

#### Electricity for Road-transport, Flexible Power Systems and Wind Power

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# VPPC 2011 6.-9. September 2011 Chicago

### Results from a study on:

### **Electricity for Road-transport** Flexible power systems and wind power

http://www.risoe.dtu.dk/en/Research/sustainable\_energy/energy\_systems/projects/SYS\_G2V2G.aspx

Lars Henrik Nielsen Senior scientist SYS Risø DTU Denmark  $f(x+\Delta x) = \sum_{i=0}^{\infty} \frac{(\Delta x)^{i}}{i!} f^{(i)}(x) = a^{i} = \frac{1}{2} \frac{(\Delta x)^{i}}{(x+\Delta x)^{2}} \frac{(\Delta x)^{i}}{(x+\Delta x)^{2}}$ 

### Risø DTU

National Laboratory for Sustainable Energy







#### **Project title:**

## Electricity for Road Transport Flexible Power Systems and Wind Power

#### Project aim:

To analyse the **potential synergistic interplay** that may arise between the **power sector and the transport sector**,

if segments the road transport are based on

### plug-in hybrid electric vehicles and pure electric vehicles,

for integrating fluctuating power production, such as wind power.

#### Partners:

- Risø National Laboratory for Sustainable Energy. Technical University of Denmark (DTU)
  Systems Analysis Division and the IES Programme.
- Technical University of Denmark (DTU). Centre for Electric Technology, Department of Electrical Engineering.
- RAM-løse edb (expertise on optimisation models / Balmorel )
- Energinet.dk, Planning & Scenarios and Analysis & Methods (Danish **TSO**)
- Danish Energy Association (Includes Danish **DSOs**)

#### Main sponsor: EUDP (Danish Energy Development and Demonstration Programme)

Project duration: 3.5 years

### Content: Touch upon

#### EV technology development assumptions

(Segment: Passenger cars and delivery vans < 3.5 ton )

- Scenarios set up for Denmark (population of about 5.5 mio.) (via EPRI medium scenario assumptions from 2007 for market penetration. Mainly focus on PHEVs.)
- Power Distribution system aspects (DSO)
- Power Transmission system issues (TSO)
- Overall (north European) power system: Future development with EVs …

Results via the power system optimisation models (including transport modules)

Balmorel (market, system operation and development (investments)) and

**Wilmar** (spot and intraday markets, system operation, stochastic production)

# Vehicle energy consumption: kWh/km

# DTU

#### **ICEV** fuel consumption:



**HEV fuel consumption:** 

**BEV electricity consumption:** 

#### PHEV electricity and fuel consumption:





# Electric Vehicle: Battery size and range per charge

#### PHEV & BEV: Range [km/charge]

#### PHEV & BEV: Battery size [kWh/pack]



# Vehicle specific CO<sub>2</sub> emission: g CO<sub>2</sub> /km

CO<sub>2</sub>Case I : Marginal el-production in DK (coal) Source: DEA (2010)

#### ICEV CO<sub>2</sub> emission:



#### PHEV CO<sub>2</sub> emission: CO<sub>2</sub>Case I



#### HEV CO<sub>2</sub> emission:



#### BEV CO<sub>2</sub> emission: CO<sub>2</sub>Case I



# Vehicle specific CO<sub>2</sub> emission: g CO<sub>2</sub> /km

**CO<sub>2</sub>Case III** : Average power system CO<sub>2</sub>-characteristics.

And linear phasing out to zero of all fossil fuels by 2050. (Stated Danish aim, October 2010.)

ICEV CO<sub>2</sub> emission:

HEV CO<sub>2</sub> emission:





# Energy price developments assumed for fuel (gasoline/diesel) and electricity.



### Vehicle cost of ownership: \$/year EV battery cost: USDOE July 2010 Scenario





![](_page_9_Figure_3.jpeg)

![](_page_9_Figure_4.jpeg)

### Vehicle cost of ownership: \$/year EV battery cost: USDOE July 2010 Scenario

![](_page_10_Picture_1.jpeg)

![](_page_10_Figure_2.jpeg)

#### PHEV: BatCost II, US DOE 2010 scenario

![](_page_10_Figure_4.jpeg)

#### BEV: BatCost II, US DOE 2010 Scenario

![](_page_10_Figure_6.jpeg)

![](_page_11_Picture_0.jpeg)

# Relative cost of ownership: (\$/year)/(\$/year) BEV, PHEV, HEV / ICEV

#### BatCost I: DK DEA 2010 scenario

#### BatCost II: US DOE 2010 Scenario

![](_page_11_Figure_4.jpeg)

# **Conclusion: Individual EVs**

Energy & CO<sub>2</sub> emission

#### Energy:

- Electricity substitutes gasoline/diesel via the EV.
- EV drive trains have potential for being very energy efficient.
- 3000 kWh electricity may sustain about 20.000 km average vehicle driving.
- Via EVs segments of the transport sector can **diversify its energy resource base** and reduce dependency on oil based fuels.

#### CO<sub>2</sub> emission:

- EV CO<sub>2</sub> emission relates to the power supply system charging the vehicles. The EV footprint of the individual vehicle change in accordance with the power supply.
- According to the Danish 'reference' development for the marginal power supply EVs bring almost insignificant CO<sub>2</sub> reduction (due to coal dominated marginal power production). However, assuming linear descend to zero CO<sub>2</sub> emission in 2050 for the power supply substantial CO<sub>2</sub> reduction is achieved via EVs substituting ICEVs. Ultimately EVs may provide zero CO<sub>2</sub> emission road transport.
- The individual ICEV of today may emit about 2-3 ton CO<sub>2</sub> /year. This equals max achievable EV CO<sub>2</sub> reduction.

# **Conclusion: Individual EVs**

![](_page_13_Picture_1.jpeg)

### Economy:

- Cost and lifetime of **EV batteries much determine the EV economy**. Based on (marginal and partial) socio-economic costs of ownership.
- In 'reference' battery cost development: PHEVs may get break-even with the ICEV beyond year 2020. (COWI (2007) & IEA (2009))
- In 'alternative' battery cost development: PHEVs may get break-even with the ICEV year 2015. (DOE, The Recovery Act: Transforming America's Transportation Sector, Batteries and Electric Vehicles, July 14, 2010.)
- CO<sub>2</sub> emission allowance costs for 2-3 ton CO<sub>2</sub> are small put relative to costs of vehicle ownership. May not constitute incentive for vehicle purchase.

### Danish fleet: Vehicle/fleet renewal

![](_page_14_Picture_1.jpeg)

### Segment: Passenger Cars + LDV < 3.5t

![](_page_14_Figure_3.jpeg)

#### **PHEV Market share** Plug-in HEV fleet split on age groups Plug-in HEV: Passenger cars and LCVs Market share and fleet development assumed

Segment: Passenger Cars + LDV < 3.5t

![](_page_15_Figure_1.jpeg)

### Danish fleet: **PHEV Scenario:** Market share & fleet development (# PHEVs)

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![](_page_15_Picture_5.jpeg)

**PHEV: Fleet development** 

### Plug-in Hybrid Electric Vehicles (PHEV):

# % of annual driving on electricity in DK?

![](_page_16_Figure_3.jpeg)

Source: Estimated (Weibull) distribution based on data from DTU Transport: 'Transport Vane Undersøgelse: 2006+2007'.

# Danish fleet: PHEV Scenario: Energy substitution

![](_page_17_Picture_1.jpeg)

(TWh/year (fuel or el.))

Segment: Passenger Cars + LDV < 3.5t

![](_page_17_Figure_4.jpeg)

# Danish fleet: **PHEV Scenario:** CO<sub>2</sub> emission

![](_page_18_Picture_1.jpeg)

### (1000 ton $CO_2$ /year)

Segment: Passenger Cars + LDV < 3.5t

**CO<sub>2</sub>Case I** : **Marginal (coal based) power supply** (DK DEA 2010)

![](_page_18_Figure_5.jpeg)

## Danish fleet: **PHEV Scenario:** CO<sub>2</sub> emission

![](_page_19_Picture_1.jpeg)

### (1000 ton $CO_2$ /year)

Segment: Passenger Cars + LDV < 3.5t

**CO<sub>2</sub>Case III :** Average power system CO<sub>2</sub>-characteristics.

And linear phasing out to zero of all fossil fuels by 2050.

![](_page_19_Figure_6.jpeg)

BatCost I : Reference

4000

3000

2000

Mio.\$/ year 0 5 1000-

-2000

-3000

-4000

(marginal & partial analysis)

BatCost II : US DOE 2010

![](_page_20_Figure_3.jpeg)

### Danish fleet: **PHEV Scenario:**

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![](_page_20_Picture_7.jpeg)

![](_page_20_Picture_8.jpeg)

![](_page_21_Picture_0.jpeg)

# Socio-economic PHEV and BEV scenarios: Limitations and assumptions made

- Issues NOT taken into account:
  - Infrastructure costs
  - Insurance costs
  - Power system flexibility gains (power system regulation capabilities, postpone investments in production/grids etc.)

#### • Externalities NOT taken into account:

- Reduced local pollution and reduced noise
- Opportunities for industry and future employment ('first mover' effects)
- Oil substitution (reduced dependency on oil)
- EVs effect on hedging for increasing oil prices (and rising transport costs).
- System robustness and flexibility. Security of energy supply (diversified transport energy basis).

Most externalities NOT taken into account tend to act in favor of the EV Note, however, infrastructure costs for EVs relative to the ICEVs are not addressed in the present analysis.

# Thank you for your attention

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![](_page_22_Picture_4.jpeg)

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