CLEAN ENERGY MINISTERIAL

Accelerating the Transition to Clean Energy Technologies

Electric Vehicle Integration in Power Systems – Challenges and Innovative Possibilities

Pre-Read for Public–Private Roundtable

Clean Energy Ministerial

12 May 2014

Seoul, Republic of Korea

Outline

1. **Objective**
2. Current Landscape and Future Scenarios
3. Barriers
4. Potential Solutions
5. Opportunities for Progress

Roundtable Objective

Participants will consider the **key technical, policy, regulatory, and market design elements** at the EV-power system interface.

Participants will discuss the **challenges and opportunities of EV-grid interactions**, and will **identify key steps** to opening up new business models, encouraging market formation, and realizing full potential benefits of EV integration into power systems.

Now is the time to prepare for EV-grid readiness: to plan proactively to manage the impacts — and maximize the benefits — of large-scale EV integration.

Solar EV Charging Station — Argonne National Lab, U.S., 2011

In this roundtable, participants will address key questions relevant to EV integration into power systems:

- What have OEMs and grid operators learned so far from the early market introduction of EVs and their interaction with power grids?
- What are the emerging technologies and business models for EV integration?
- What are the most critical challenges for large-scale deployment and integration of EVs in power systems?
- What is the optimal amount and level of charging infrastructure?
  - *For power system integration?*
  - *To reach EV deployment targets?*
- What unique challenges and opportunities arise in emerging economies for EV integration?

Scope of Roundtable (2 of 2)

In this roundtable, participants will address key questions relevant to EV integration into power systems:

- What constructive roles could organized EV charging play in the operation of power markets?
  - *In integrating renewable energy?*
  - *In encouraging grid resiliency?*
- How can policymakers and regulators create better frameworks and incentives for EV–grid integration?
- What are priority areas for public-private coordination?
- What are the benefits of international standards for EV integration into electricity networks, and how will international alignment encourage market growth?

The Vision

Successful EV and smart grid integration means:

- **Grid infrastructure does not constrain EV scale-up**, but rather supports it.
- EVs **"do no harm"** to the grid. They can charge (and potentially discharge) without affecting reliability.
- EVs bring **public benefits** (e.g., emissions and petroleum reduction).
- EVs bring **benefits to customer homes and buildings** (e.g., auxiliary power, resiliency, reduced energy costs).
- EVs bring **benefits to the grid**, providing grid services (e.g., voltage support, ancillary services) and supporting renewable energy integration (e.g., through managed charging).

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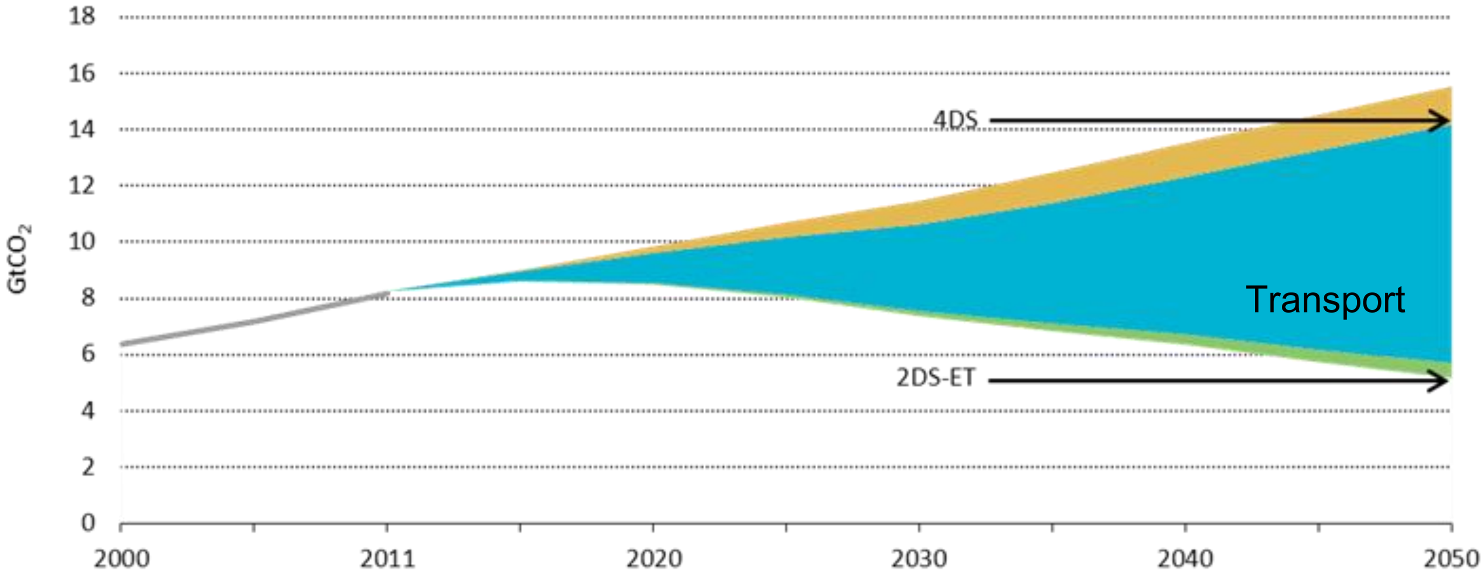
The Role of Transport in Global CO_2 Reduction

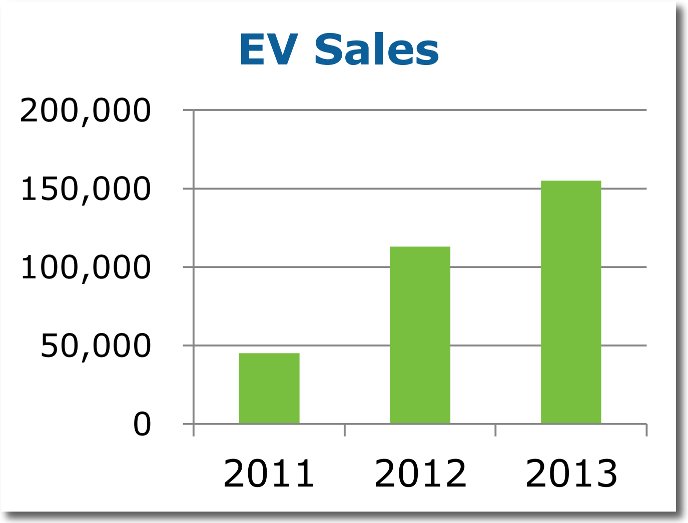
- Transport reductions represent **21% of target emissions reduction** under the IEA 4°C Scenario (i.e., scenario describing a future energy system that would limit average global temperature increases to 4°C by 2050). (ETP 2012)
- Compared to the 4°C Scenario, **achieving a 2°C Scenario requires significantly more CO_2 emissions reductions from transport.** (ETP 2014)
- EV contribution to transport emissions reduction is **strongly dependent** upon **rate of EV adoption** and upon **emissions profile of source electricity.**



6DS = 6°C Scenario
4DS = 4°C Scenario
2DS = 2°C Scenario
2DS-ET = 2°C Scenario with high-EV penetration

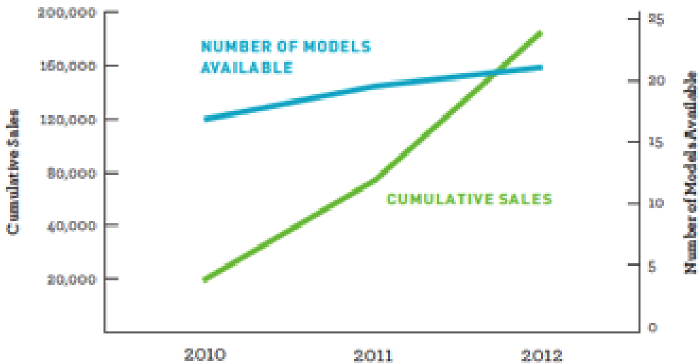
Current Progress of Global EV Deployment

- Global EV stock now stands at approximately 335,000.
- However, EVs represent just 0.02% of global light-duty stock.
- Grid stress is minimal now. Utilities — even in the leading EV markets — are not reporting problems.
- As cost of batteries continues to fall, deployment may accelerate dramatically.



(Source: EVI)

Global EV Model Diversity and Sales

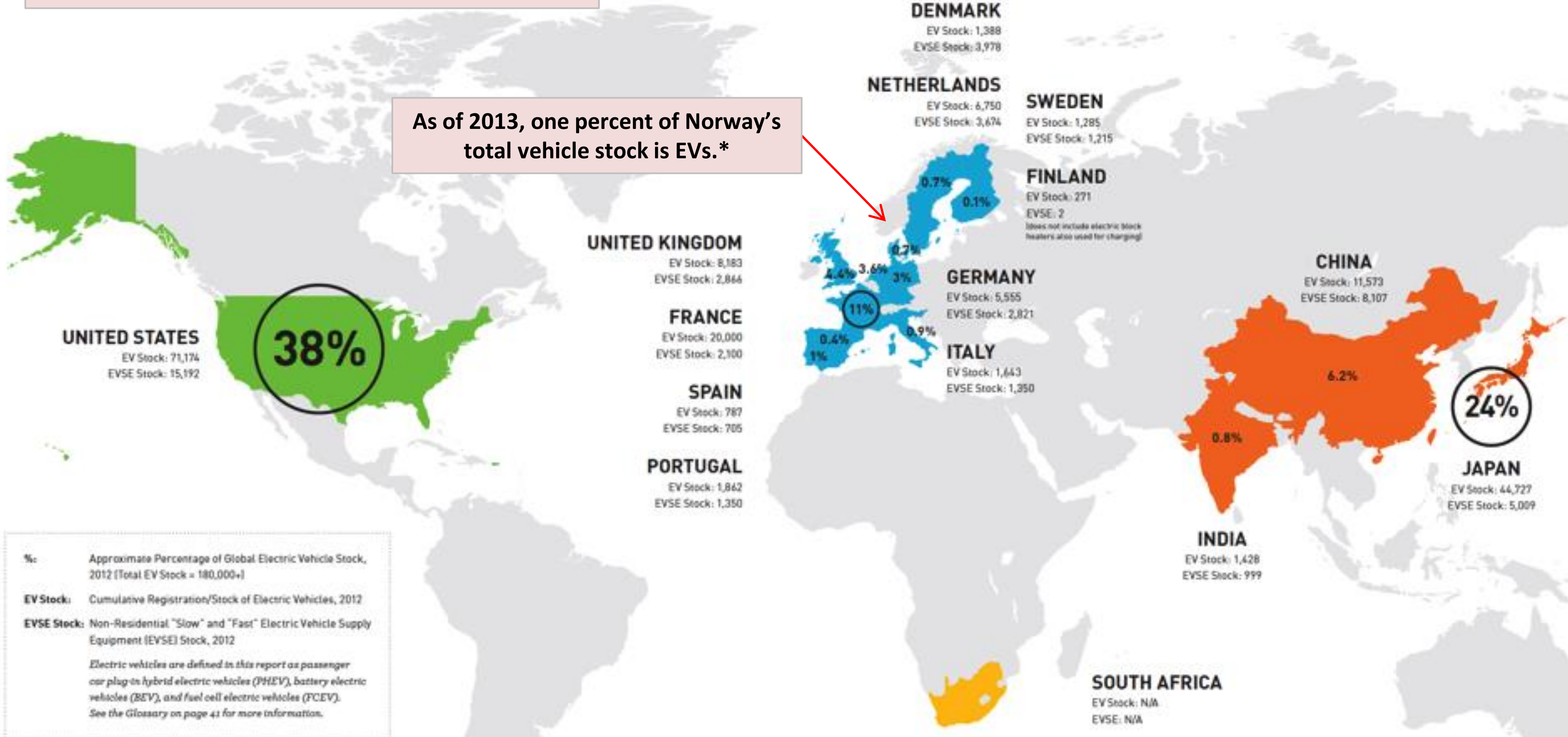


(Source: EVI)

Major EV Markets

At the end of 2012, member countries of the Electric Vehicles Initiative (EVI) accounted for 90% of global EV stock

2012 figures; % = global share



*Norway is an EVI observer country.

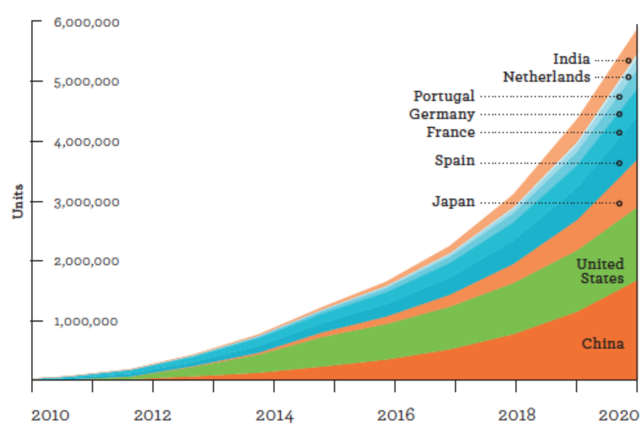
Targets

Sales and stock targets in EVI countries

- **Aggressive EV and EVSE targets** are in place in many major economies.
- **Both policy and market drivers:** governments and automobile OEMs are both supporting electrification.

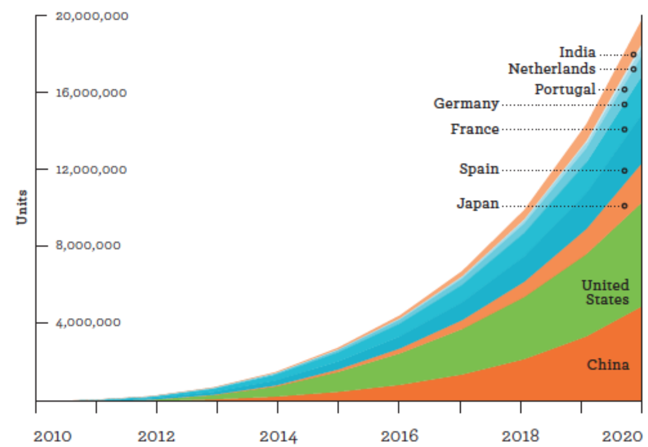
Sales Targets

Source: EVI. Note: A 20% compound annual growth rate is assumed for countries without a specific sales target (i.e., only a stock target) or with targets that end before 2020.



Stock Targets

Source: EVI. Note: A 20% compound annual growth rate is assumed for countries without a specific stock target (i.e., only a sales target) or with targets that end before 2020.



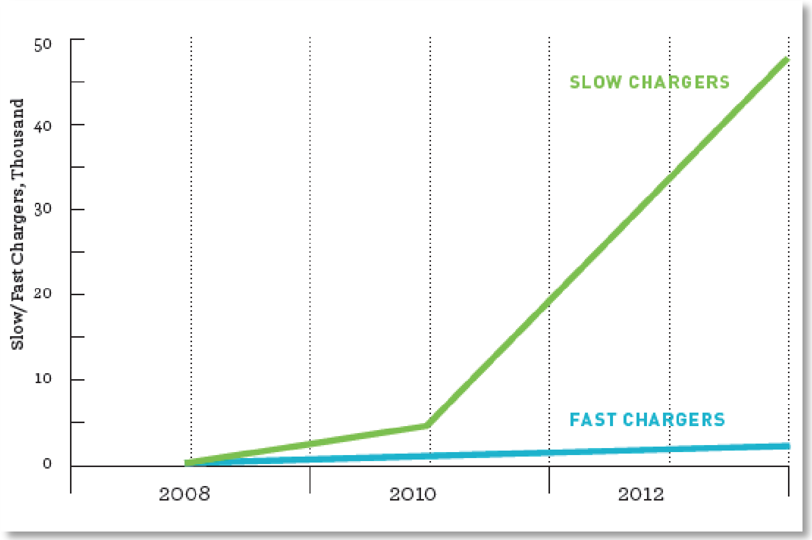
- **Economic drivers** include falling battery prices, volatile fuel prices, and competition for global EV market share.

EV Supply Equipment (EVSE) Deployment

Recent Trends in Fast and Slow Charging EVSE

- **Slow charging infrastructure is dominant.**
- **EVSE-to-EV ratio** varies by country and by charging type, but is important to track to ensure optimal EVSE deployment.
- **Limited need for fast charging?**
  Early research suggests well-designed systems would need only a few fast charging stations instead of blanketing a wide area. (Nicholas et al. 2012)

Fast and slow (non-Residential) EVSE/EV Ratio in EVI countries (Source: EVI)



Trends in EVSE deployment in EVI countries (Source: EVI)

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EVSE Network and Payment Standards

Recent Trends

Multi-standard, cloud-connected

- Some EVSE systems are compatible with multiple charging systems, management networks and payment platforms
- e.g., ABB's "Terra 53" fast charger meets both SAE Combo and CHAdeMO standards, and communicates through open standards-based interfaces, such as Open Charge Point Protocol (OCPP)
- But this is not always the case: some manufacturers and EVSE service providers prefer independent, proprietary systems, which limits interoperability

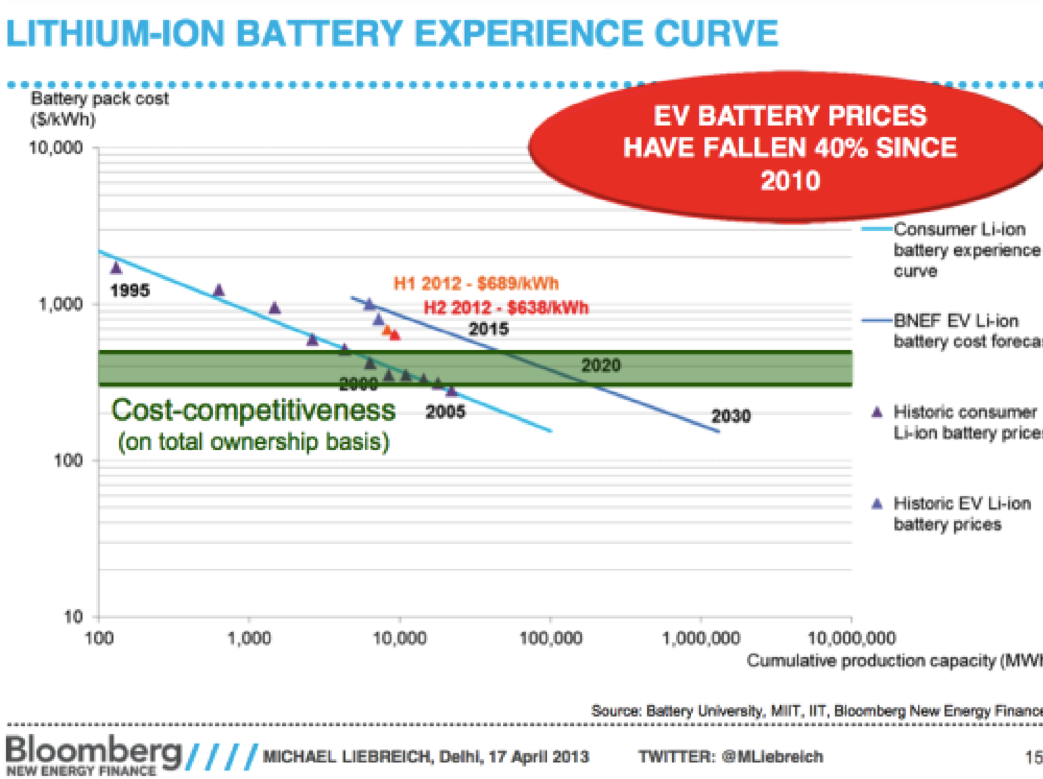
EV Charging Point — Newcastle-upon-Tyne, U.K., Autumn 2011

Smart Charging Station — Frankfurt, Germany, September 2011

CURRENT STATUS: BATTERY PRICES

Recent Trends: Scale and Disruption

- Experience curve projections indicate continued declines from ~$700/kWh in 2010 to **~$220/kWh in 2020** (McKinsey 2012)
- 2014 prices may fall below **$400/kWh** (CleanTechnica 2014)
- Cost declines driven by **demand from multiple markets** (EVs, aerospace, personal electronics, home energy storage) resulting **in economies of scale**



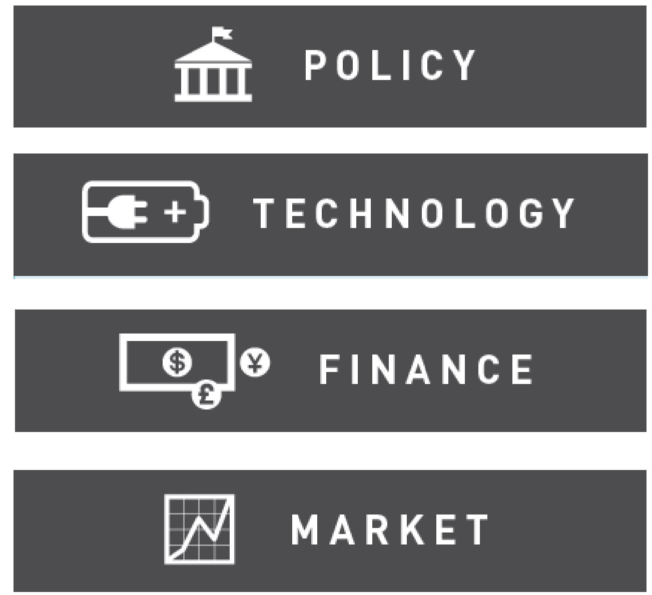
- **Disruptive innovation**
  BMW board member:
  "In the next three to four years there will be more progress in battery development than in the previous 100 years"

Illustrative example – cost reductions for consumer (non-EV) Li-ion batteries:
- *2000: $2.60/Wh* ***($2600 per kWh)***
- *2012: $0.20/Wh* ***($200 per kWh)***

The Role of Policy in EV Readiness

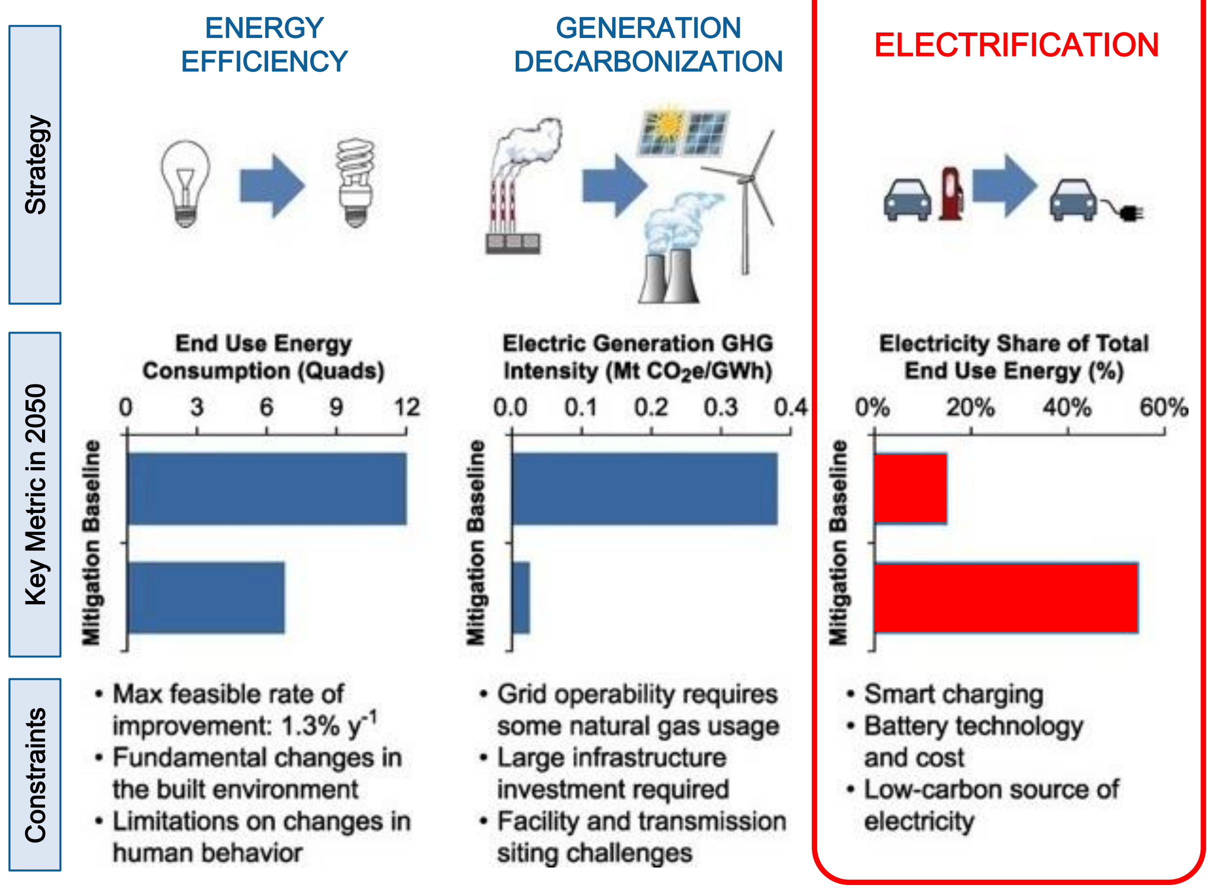
Adoption rates, EV readiness, and policy drivers

- **Policy is currently the prime driver** of EV adoption, but economic drivers are increasing.
- **Various policy instruments are employed** by governments to accelerate EV adoption and promote EV readiness, including supply- and demand-side subsidies, public procurement, and EVSE deployment.
- **Economic value and customer experience will play an increasing role** in adoption rates.
- **Policy action and technical innovation are needed to ensure power system readiness for large-scale EV deployment.**



The Role of Transport Electrification in Future Energy Systems

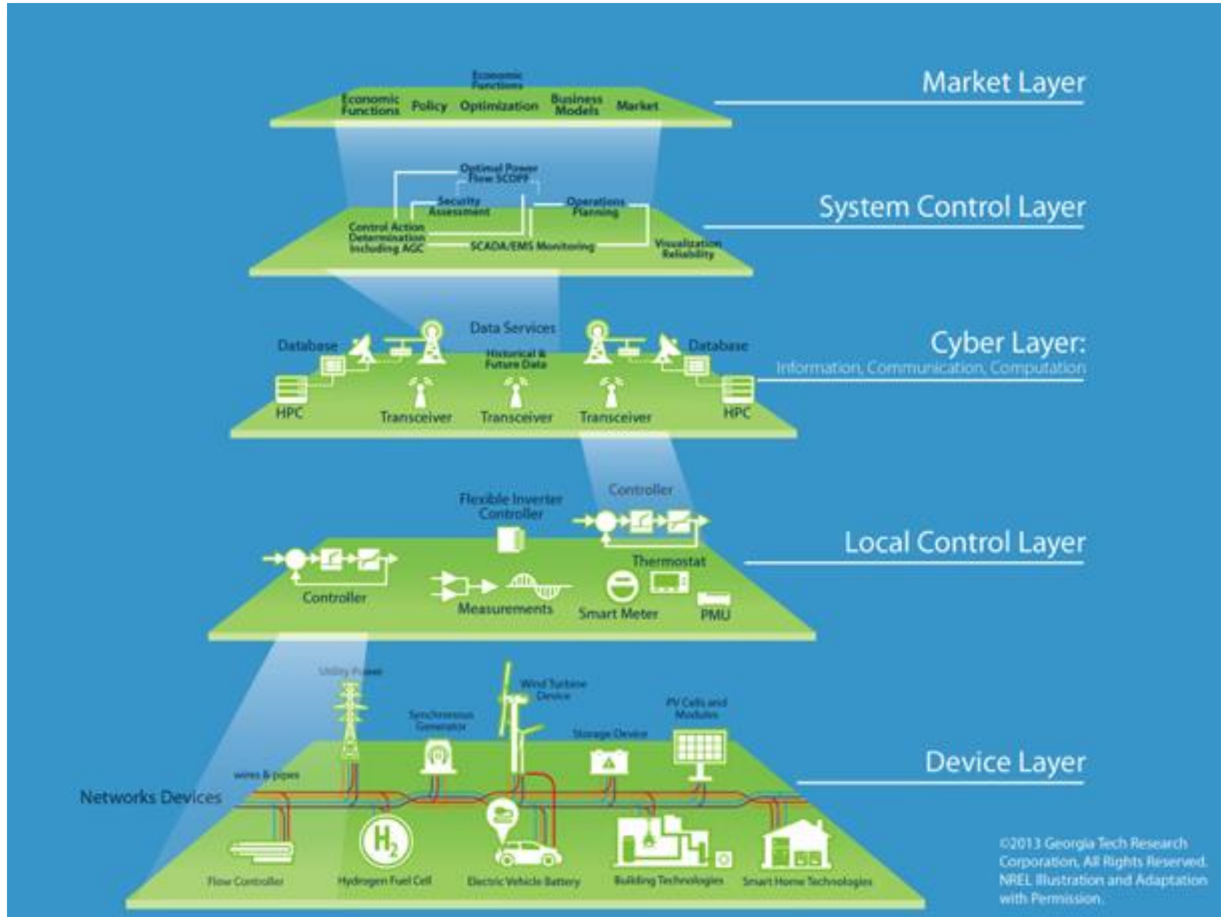
- In scenarios replacing petroleum with electric transportation, **electricity becomes the dominant component of the 2050 energy economy,** and the cost of decarbonized electricity becomes a paramount economic issue.
- **Acute need to ensure power systems that are clean and can handle EV scale-up.**



Williams et al. (2011). The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity. *Science*, 335(6064), 53–59. *Emphasis added.*

Interactions with the Power System

- EVs are considered an **important component in 21st century power systems** – but cannot be viewed in isolation.
- A **holistic systems perspective** is needed in order to understand market and customer impacts.
- Near-term focus is on promoting **innovation across the market, system control, local control, and device layers.**



Schematic Illustration of Future Energy System Architecture
(NREL 2013)

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Power System Impacts

Low- and Medium-Voltage Grid Impacts

- At low market penetrations, “EVs have only a minor impact on the network in terms of distribution system losses and voltage regulation but more importantly the vehicle owner's costs are roughly halved.” (Ma et al. 2012)
- At higher penetrations, grid impacts mainly arise in the form of **load curve impact, network congestion, network losses,** and **voltage violations.**
- **These impacts depend largely on EV penetration levels and charging strategies.**
- Unmanaged charging will likely exacerbate peak loads and potentially require extra investment in generation and transmission capacity.

Illustration of Daily Load Curve with 10% EV Penetration (Source: Lopes et al. 2011)

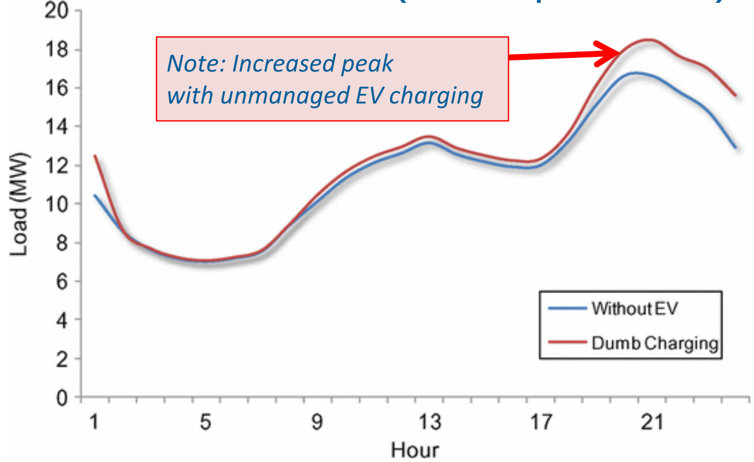
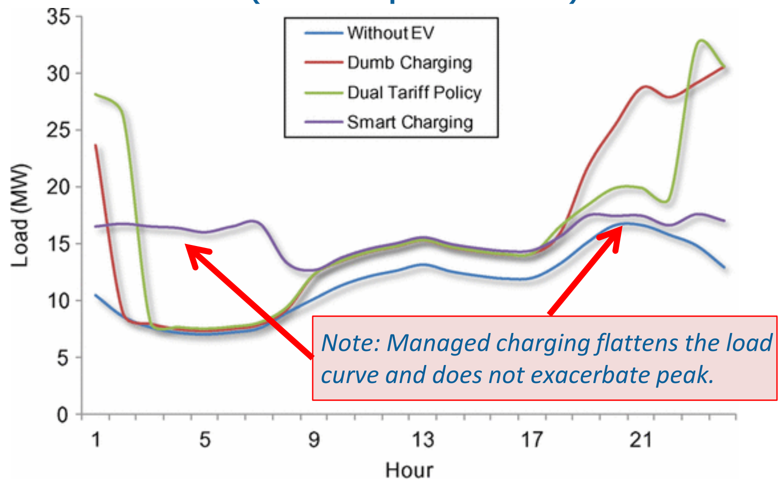


Illustration of Daily Load Curve with 52% EV Penetration under Three Charging Strategies (Source: Lopes et al. 2011)



Power System Impacts

Low- and Medium-Voltage Grid Impacts

- Strategic charging approaches could mitigate peak load impacts and postpone grid investment needs.

  Example approaches include:
  - **Dual tariffs:** lower tariffs during off-peak hours to incentivize low-impact charging
  - **Managed charging** by the distribution system operator or third party (aka **"smart" charging**)
- Simulations suggest **smart charging is relatively more effective in mitigating grid impacts** (peak-load, congestion, losses, etc.)**.**
- Smart charging **does not prevent all need for grid reinforcement, but rather delays it** until higher EV penetrations are reached.
- Achieving smart charging is not (only) a hardware problem. It requires **significant innovation** in **system operation, business models, and regulatory frameworks.**

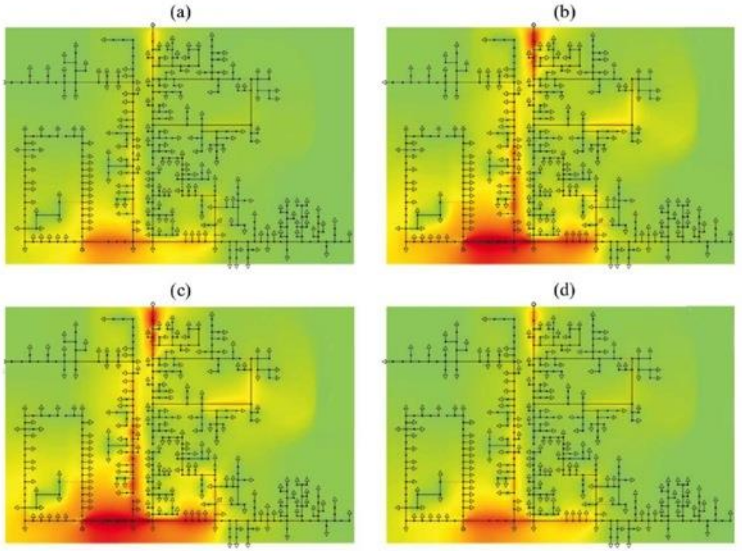


Illustration of network congestion under four scenarios: (a) No EVs, (b) 52% EVs with dumb charging, (c) 52% EVs with dual tariff policy, and (d) 52% EVs with smart charging. (Source: Lopes et al. 2011)

Potential Benefits to the Power System

EVs as Virtual Power Plant (VPP)

Aggregating and managing electrical loads for charging EVs hold the promise of:

- Facilitating the grid integration of renewable energy
- Enabling flexibility into the system
- Optimizing the efficient use of generation capacity
- Deferral or avoidance of grid investments and generation capacity investments

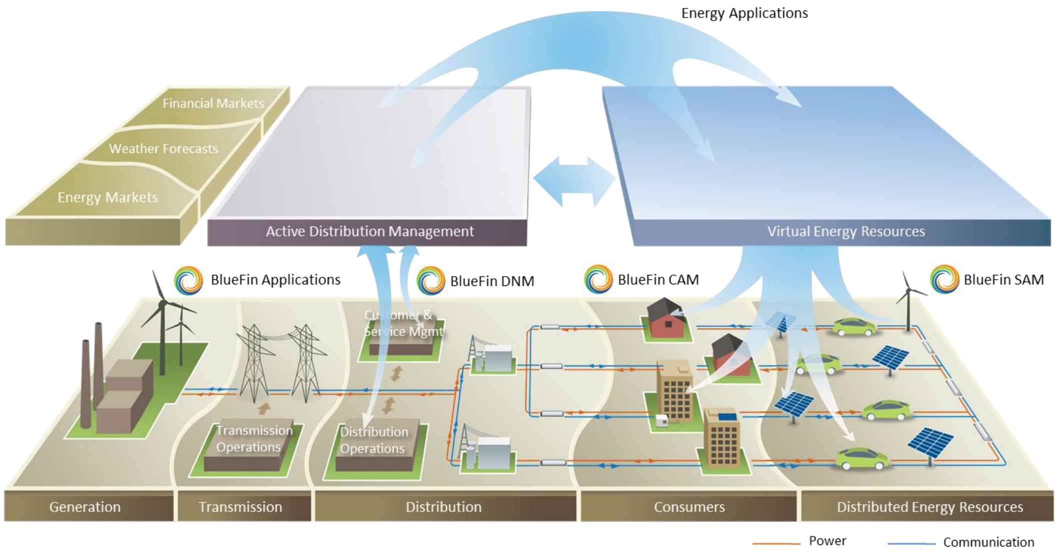


Illustration of DERs as a virtual energy resources (Source: Spirae 2013)

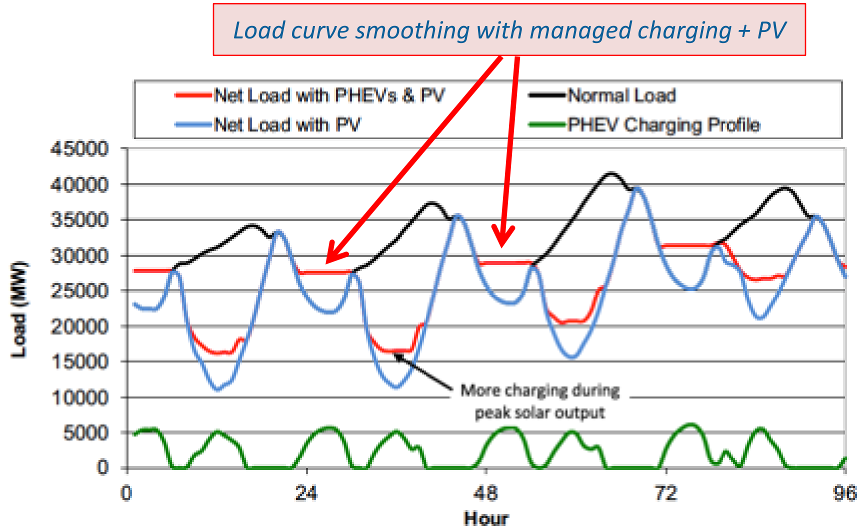
Under a VPP conception, many distributed energy resources (DERs) of small sizes can be **aggregated and networked to act as one grid-connected generation plant, thus allowing entry into electricity markets** that usually have a minimum-capacity threshold (e.g., 1000 kW).

Potential Benefits to the Power System

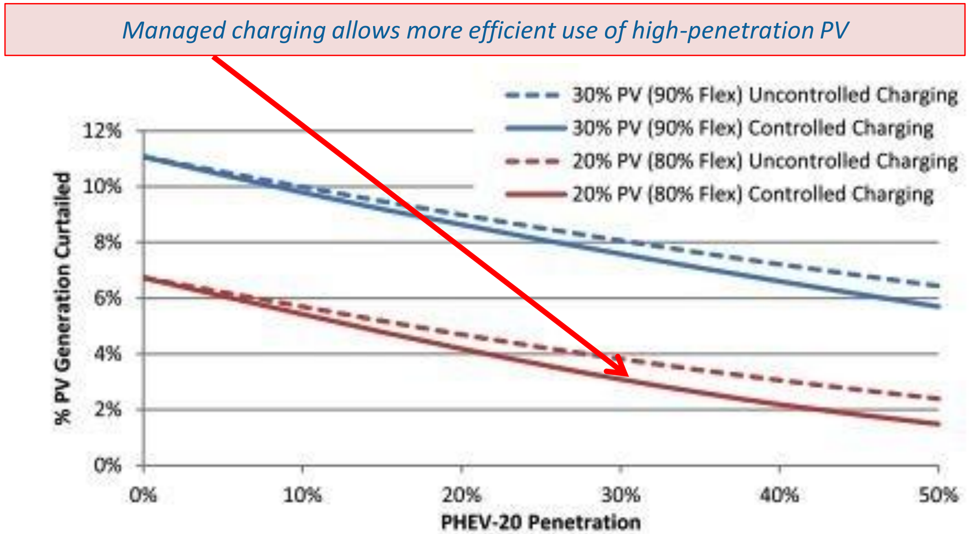
Co-Benefits of EVs and PV through Managed/Smart Charging

Case Study: PV Integration

- Controlled charging designed to take advantage of midday electricity available from solar PV brings benefits including significant reductions in PV curtailment and reductions in costly peak capacity additions.
- **Policy, technical, and market solutions are all needed to implement controlled charging.**



Net load with 30% PHEV penetration, 15% PV penetration, and controlled "late" charging (Source: Denholm, Kuss and Margolis, 2013)



Decrease in PV curtailment as a function of PHEV penetration (Source: Denholm, Kuss, and Margolis, 2013)

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Barriers to Full EV-Power System Integration

Barriers in three separate but related categories:

- **Accelerating Adoption**
  Slow adoption rates will reduce overall emissions impact and opportunities for grid support.

- **Facilitating Power System Integration**
  Rapid adoption rates will elevate importance of integration issues.

- **Maximizing Power System Benefits**
  Successful power system integration will not guarantee maximal power system benefit. Additional technical, policy, and regulatory innovation will be needed to unlock full system potential.

BARRIERS TO FULL EV-POWER SYSTEM INTEGRATION

Accelerating Adoption

Customer adoption:
- Higher up-front costs
- Range anxiety, charging control, lack of privacy (e.g., due to vehicle tracking), etc.

EVSE investment:
- Incentives for personal and public charging
- Optimal siting of infrastructure to encourage use and avoid stranded assets
- Battery-swapping vs. charging *(though global trend is charging)*

Interoperability:
- Ensuring EVSE compatibility with *all* utility infrastructure

Regulatory frameworks:
- Tiered demand charges support energy efficiency but may deter EVSE investment

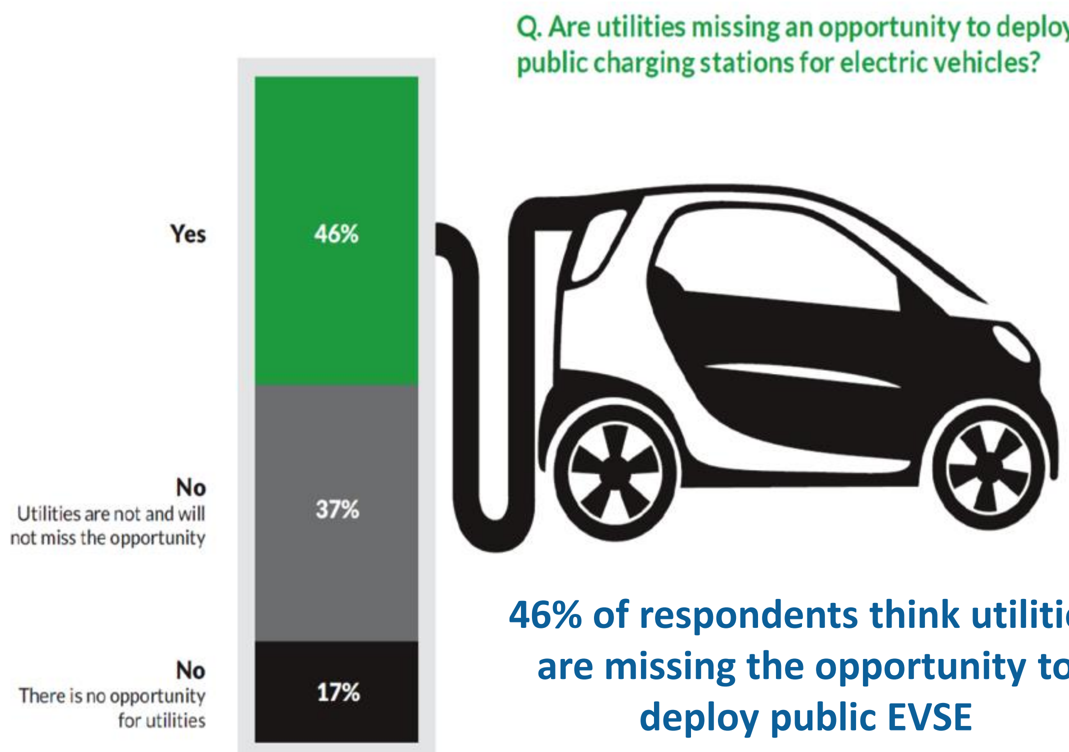
Automaker risk:
- Battery warranty concerns may arise with controlled charging, reverse flow (V2G) applications

BARRIERS TO FULL EV-POWER SYSTEM INTEGRATION

Facilitating Power System Integration

Reducing Utility Risk:

- Clear market models, e.g., eligibility and rules for controlled charging entities, price discovery, etc.
- Assessing location and time clustering of EVs, and potential local distribution stress
- Standards-based solutions for service providers to ensure devices from multiple manufacturers can be integrated (interoperability)
- Common clearinghouses needed for charging across different networks (similar to mobile phone roaming)



46% of respondents think utilities are missing the opportunity to deploy public EVSE

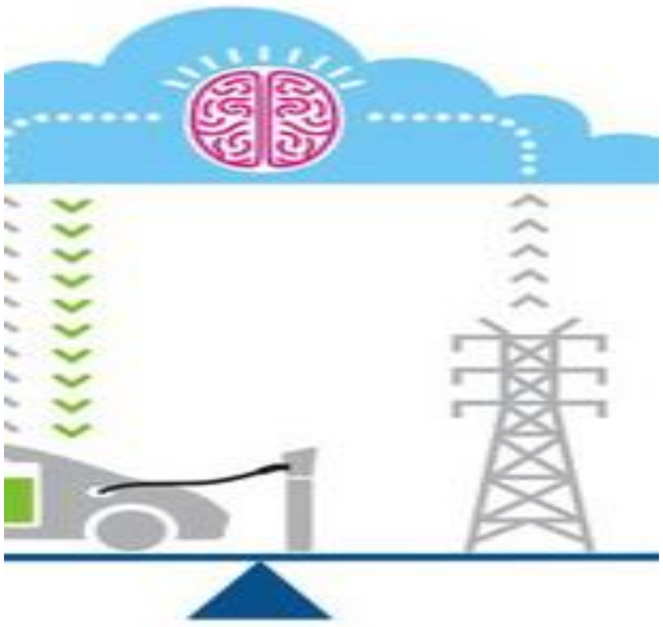
Source: Siemens "The State of the Electric Utility" Survey, 2013

Barriers to Full EV-Power System Integration

Facilitating Power System Integration

Facilitating Smart Charging:

- Behavioral and driver usage barriers to managed charging (e.g., privacy concerns)
- 1 – 2 charge posts per vehicle will result in thousands of nodes which will need to be monitored and managed
- Data and analytics to manage electric vehicles, taking into account load forecasting
- Development of algorithms for optimized charging (control of timing, pace, and extent of vehicle charge)



Establishing Scalable Financial Settlement Systems That Support:

- Multiple price inputs (time-based for energy, variable price for controllability, reservation fees, location/speed of charging premiums)
- New taxation mechanisms (energy-based, distance-based)
- Multiple payment options (transaction, subscription, prepaid)

(Source: IBM 2013)

Nexus: Technical, Regulatory, & Financial Barriers

Facilitating Power System Integration

Innovation and Policymaking Across Jurisdictional Boundaries:

EVSE deployment poses unique regulatory challenges, as it spans multiple jurisdictions. Generally speaking, 4 locations of EVSE:

1. **Public charging station on public domain** (e.g., on curb)

2. **Public charging station on private domain** (e.g., commercial areas such as shopping malls)

3. **Semi-public charging station on public or private domains** (e.g., car sharing, hotels, or business parking for visitors and customers)

4. **Privately accessible charging station** (e.g., home or office locations)

(Source: Eurelectric 2013)

Barriers to Full EV-Power System Integration

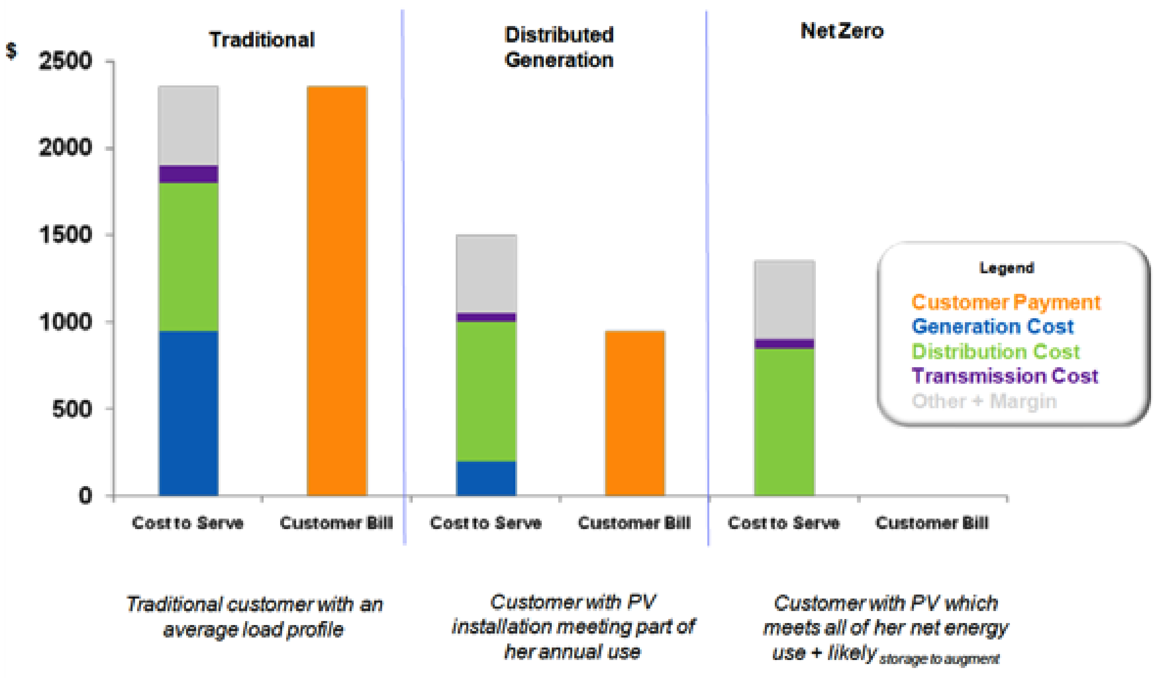
Maximizing Power System Benefits: *Encouraging Utility Innovation*

In light of growing energy efficiency and distributed PV generation, **utility revenue is under downward pressure.**

Some utilities view **"EV services" as source of additional revenue** and competitive differentiation:

- New source of electricity demand
- Deploying charging stations provides additional assets for a regulated rate base or new profit centers
- A way to bolster grid needs and smooth renewable energy variability (given a business model that enables smart charging)

Costs in Serving Electricity Consumers vs. Consumer Bills, Three Scenarios



Source: IBM 2013

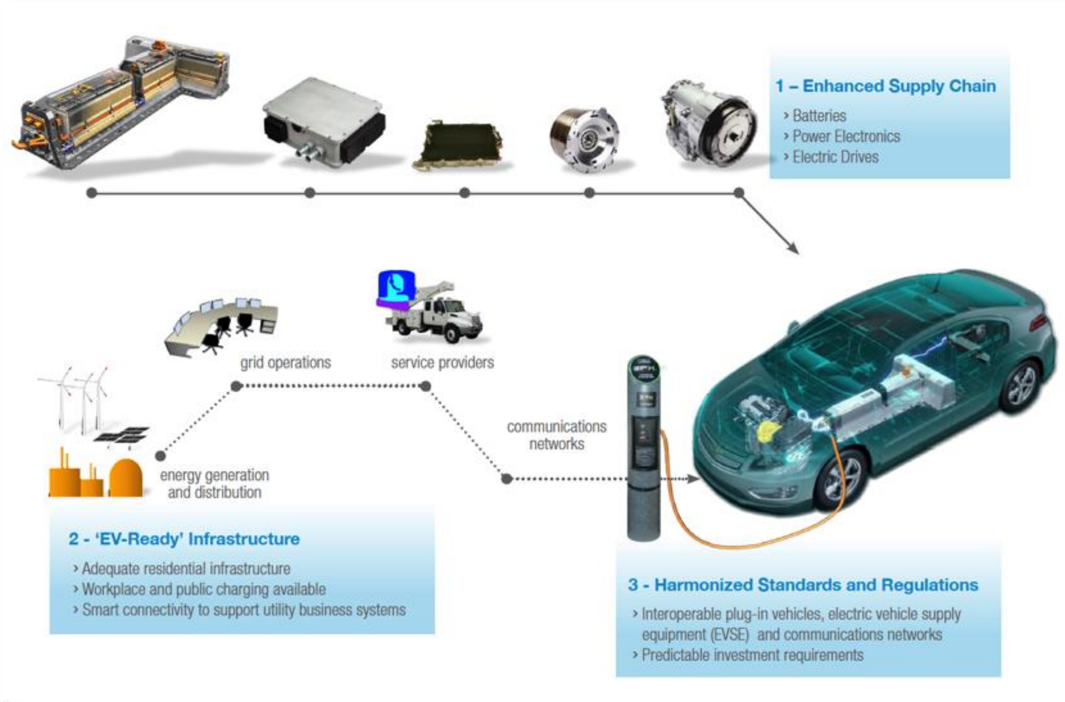
Barriers to Full EV-Power System Integration

Maximizing Power System Benefits: *Encouraging Market Formation*

- **How should EV and charging markets be organized?**
  This question affects the types of allowable fees, cost recovery methods, market actors and their roles, and customer engagement modes.

- **Market formation** requires conditions conducive to supply chain development, entry of new market participants, long-term investment, transparent pricing, and revenue creation that reflects value added, etc.

- **Lack of market formation will result in under-investment in EVSE infrastructure.**



Priority Domains of EV and EVSE Market Formation
(Source: EV-Smart Grid Interoperability Centers, US-EU Collaboration)

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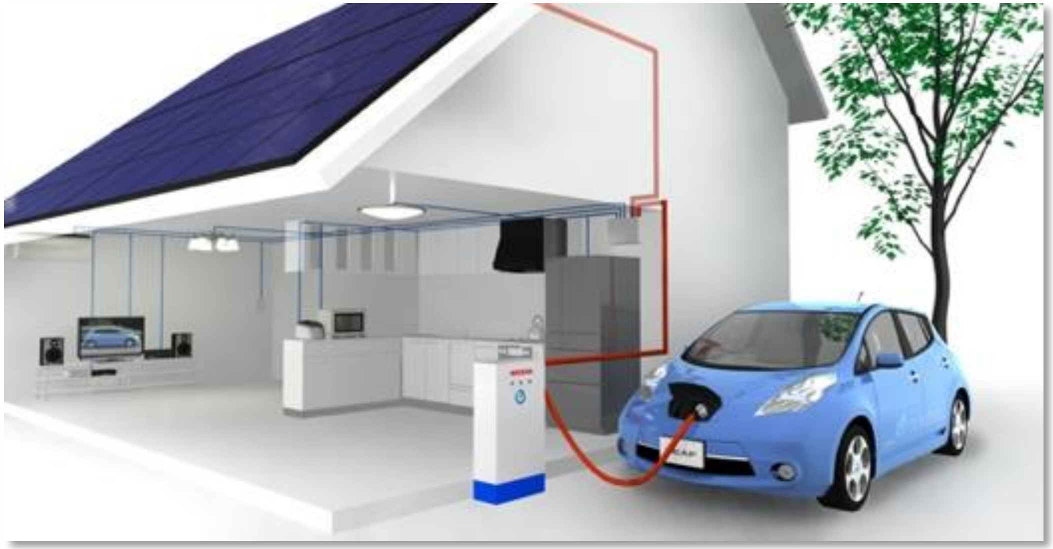
Potential Solutions

New Business and Financial Models; Added Value for Consumers

Innovative Business Models

- **Vehicle-to-home systems:** Nissan has sold 1400+ V2H systems in Japan
- Tapping latent demand for resilient backup power in face of natural disaster threats



Source: Nissan 2014

Innovative Financing

- **Green Bonds:** Toyota currently raising $1.75 bn to finance car loans for EVs and HEVs
- Tapping latent demand for stable, low-risk green investments

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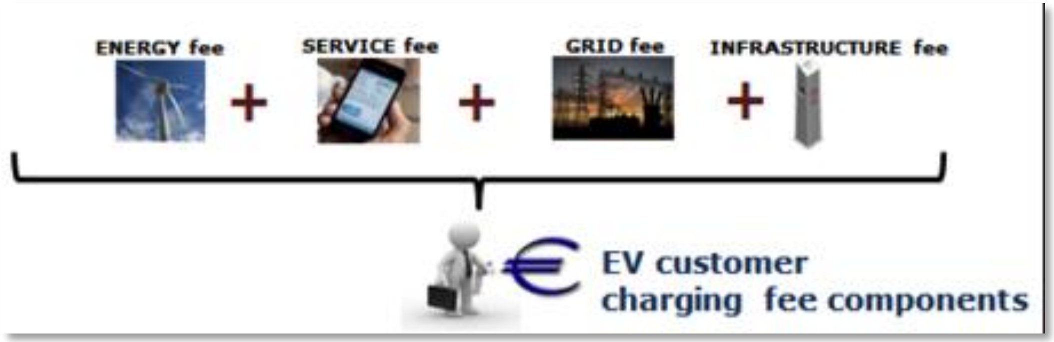
Potential Solutions

Innovative Market Models

Case study: "Independent e-mobility market model"

- Public charging stations are deployed independently from the "regulated" distribution system operator/grid business.
- Charging services are competitive services that can be offered by any market participant, even in the same city block.
- If distribution network capacity limitations occur, a smart charging process is triggered.
- Currently being implemented in Germany, France, Spain, Denmark and the Netherlands.



Components of customer charging fees in an example market model: "The independent e-mobility market model" (Source: Eurelectric June 2013)

> **"A well-organised e-mobility market is a prerequisite for smart charging."**
> (Eurelectric 2013)

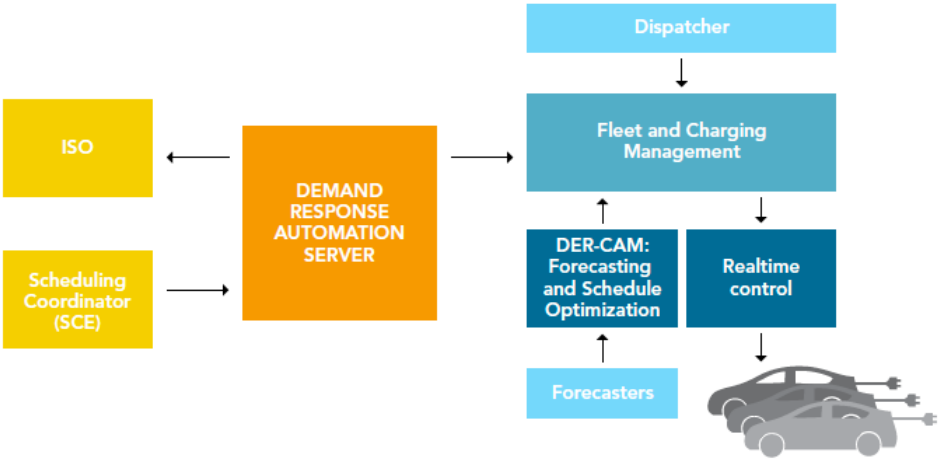
Other market models discussed in Eurelectric (2013).

Potential Solutions

Innovative Business Models

Case study: Los Angeles Air Force Base demonstration of vehicle-to-grid (V2G) capabilities

- Optimal charging and bidding into wholesale regulation markets of a fleet of EVs
- EV integration into energy system to examine potential role in base microgrids
- Optimizing charging and discharging schedule of EVs to minimize energy costs and maximize demand response and ancillary services markets



Modeling to optimize charging and discharging of Los Angeles Air Force Base's fleet of EVs

DER-CAM (Distributed Energy Resources Customer Adoption Model): optimizes individual EV charge-discharge and determines optimal day-ahead regulation bids

Demand Response Automation Server: delivers instructions using OpenADR, a widely used protocol for delivering grid signals to controlled loads; DRAS passes energy price information and transmits telemetered electricity consumption data

Scheduling Coordinator: passes bids, awards and settlements between DRAS and ISO, which operates regulation market, receives and awards regulation bids to competing resources

Potential Solutions

Integrated Planning

EV–grid integration can be mutually beneficial, but **integrated planning, technological innovation, and investment are needed** to ensure that EVs do not stress the grid *and* that full benefits are achieved.

Electric power systems already face a growing range of challenges. Integrated policy, technology, and finance planning can **transform EV integration from "just another challenge" to a genuine source of opportunity.**

Although impact is low now, **this is precisely the time for policymakers, regulators, and corporate leaders** to be pro-active to ensure smooth scale-up and integration.

Potential Solutions

Deepening Interoperability and Standards Development

Increased commitment to international standards, protocols, and interoperability, for example:

- **IEC TC 69**: Electric road vehicles and electric industrial trucks
- **IEC 62196**: Electrical connectors and charging modes for electric vehicles
- **IEEE P2030.1**: Guide for Electric-Sourced Transportation Infrastructure
- **Open Charge Point Protocol (OCPP)**: open protocol for communication between EV charging stations and a central management system
- **EPRI Infrastructure Working Council**
- **EV-Smart Grid Interoperability Centers** (European Commission and U.S. DOE)

Potential Solutions

Expanding International Collaborations

Elevated commitment to multilateral RD&D initiatives, for example:

- EU Green eMotion
- Collaboration between Governments of Japan and Mexico with Nissan

Commitment to Knowledge Sharing through International Policy Collaborations, for example:

- *CEM Electric Vehicles Initiative (EVI)* Global EV Outlook
- *IEA/CEM–International Smart Grid Action Network (ISGAN)* international research facility network
- *IEA–Hybrid and Electric Vehicles (IEA-HEV)* task on fast charging
- *IEA-HEV/EVI/Rocky Mountain Institute* EV City Casebook
- *APEC Energy Working Group* Energy Smart Communities Initiative (ESCI)

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Opportunities For Progress

1. ***Strengthening Standards & Interoperability***
   Coordinating standardization and interoperability of EV and EVSE technologies will accelerate innovation, facilitate customer adoption, ease integration into power systems, and support the realization of power system benefits.

2. ***Cost & Benefit Analysis and Research***
   International collaboration to advance methodologies of assessing costs and benefits of EV integration into power systems will clarify the basis for sound policy and regulatory decision making. Quantifying the co-benefits of EV integration with regard to variable renewable energy (e.g., solar and wind) and to system resiliency (e.g., backup power) are of particular interest.

3. ***Establishing a Global Library of EV Integration Case Studies***
   Organizing resources will accelerate the use of best practices in EV integration. Easily searchable case studies should move beyond EV/EVSE deployment figures to include more empirical cases of more sophisticated issues such as utility business models and experimental research on EV market model formation, building upon, e.g., the 2012 EV City Casebook.

Opportunities For Progress

4. ***Concrete Efforts to Encourage Utility Innovation***
   Robust utility participation in EV integration, and the development of new utility energy service models, are likely to be a key areas of progress toward realizing full power system benefits of EVs. Policy and regulatory actions can create platforms for reducing risks of utility innovation.

5. ***Concrete Efforts to Encourage Regulatory Innovation***
   Regulatory innovation will be vital, not just to remove barriers, but also to accelerate and encourage EV deployment and integration into power systems. Critical areas include assessment of business cases for EV and vehicle-to-grid systems, tariff design to encourage EV electricity usage, market model formation, and establishing eligibility for participation in bulk power system functions.

6. ***Continued Efforts to Encourage Technology Innovation***
   Research and development will be critical to lowering costs and expanding deployment. Critical areas include bi-directional EV charging, grid-friendly EVSE technology, distribution management schemes, managed charging schemes, and transactive market designs for signaling the marginal value of grid storage and charging.

CONTACT INFORMATION

Paul Telleen (EVI)
U.S. Department of Energy
Paul.Telleen@hq.doe.gov

Russ Conklin (ISGAN)
U.S. Department of Energy
Russ.Conklin@hq.doe.gov

Daniel Noll (21CPP)
U.S. Department of Energy
Daniel.Noll@hq.doe.gov

Mackay Miller
National Renewable Energy Laboratory (NREL)
Mackay.Miller@nrel.gov