Smart Grid: An Estimation of the Energy and CO_2 Benefits

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Scope and Methodology of the Study

- *Question*: Does a smart grid have a substantial role to play in the nation's carbon management agenda?
- *Goal*: Estimate the range of potential energy and carbon benefits attributable to a smart grid
- *Nine mechanisms* for a smart grid to help reduce energy and carbon were investigated
- *Two classes of benefits* reducing in energy consumption and emissions resulting …
  - *directly* from smart grid applications
  - *indirectly* from reinvestment of cost savings for renewables or efficiency programs
- *Other potential environmental benefits not examined* (air emissions, land use, etc.)

Primary Results from Study by PNNL

Mechanism	Electric Sector Energy CO_2 Reductions	
	Direct	Indirect
Conservation Effect of Consumer Information and Feedback Systems	3%	-
Joint Marketing of Efficiency and Demand Response Programs	-	0%
Diagnostics in Residential and Small/Medium Commercial Buildings	3%	-
Measurement and Verification for Efficiency Programs	1%	0.5%
Shifting Load to More Efficient Generation	< 0.1%	-
Support Additional Electric Vehicles (EVs) / Plug-In Hybrid Electric Vehicles (PHEVs)	3%	-
Conservation Voltage Reduction and Advanced Voltage Control	2%	-
Support Penetration of Solar Generation (RPS > 25%)	(1)	(2)
Support Penetration of Wind Generation (25% RPS)	< 0.1%	5%
Total, Share of U.S. Electric Sector Energy and CO_2 Emissions	**12%**	**6%**

EPRI's *Green Grid Report* estimates (direct-only) reductions in range of 2% to 7% at less than 100% smart grid penetration

* Assumes 100% penetration of smart grid in 2030; lower penetration produces proportionately smaller impacts

- Considerable uncertainty exists for each mechanism investigated: typically ~ ±50%
- Note EPRI investigated somewhat different mechanisms, on a different basis

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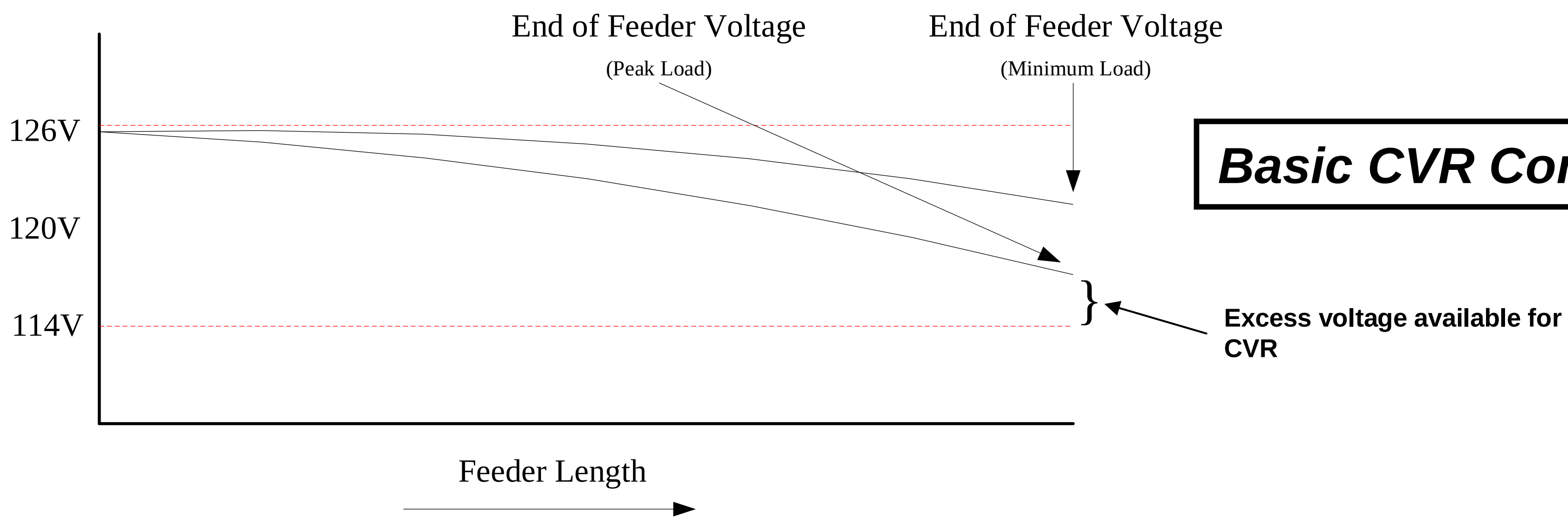
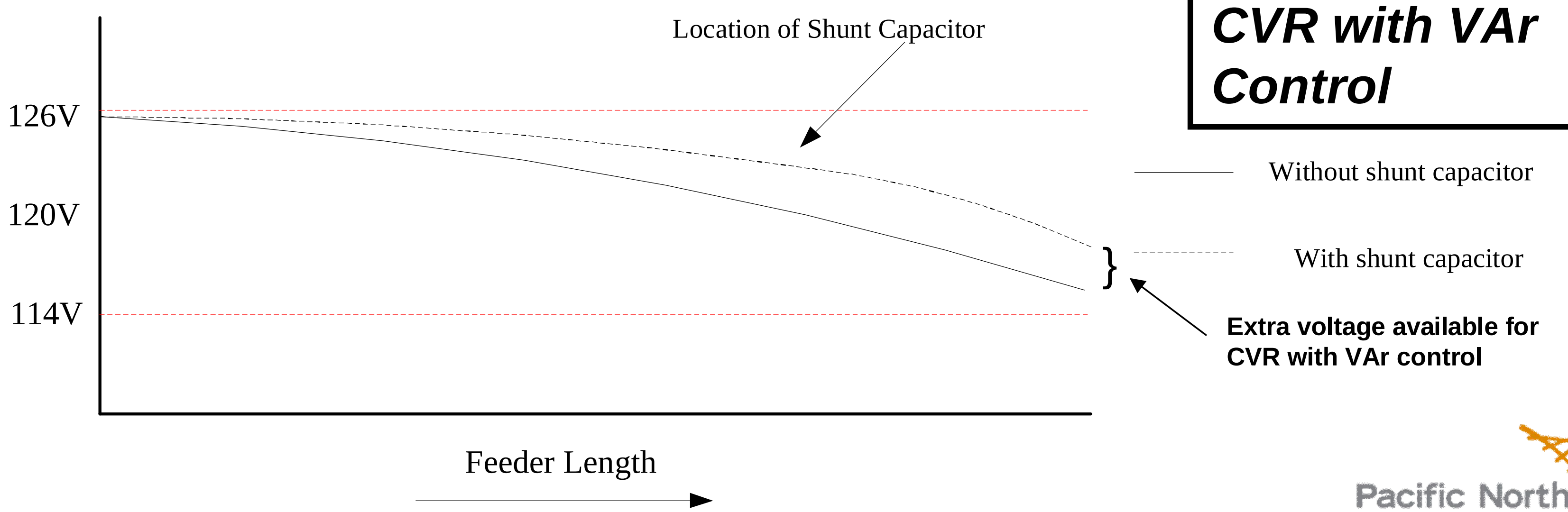
Mechanism G: Conservation Voltage Reduction and Advanced Voltage Control



Basic CVR Control



CVR with VAr Control

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Mechanism G (cont): Conservation Voltage Reduction and Advanced Voltage Control

- Optimizing voltage reduces consumption and lowers distribution losses
  - Precise control maintains voltage at end of feeder at minimum standard level
  - Lower supply voltage reduces some end-use consumption (e.g., lighting, motor winding losses)
  - Better reactive power (VAr) control reduces losses by lowering current, and raises voltage at end of feeder (more CVR potential)
  - Cost of implementation is low
- *Potential* (electric sector)*:*

Sector	Est.	Low	High
Total Electric Supply	2%	1%	4%

- *Basis:* Total distributed electricity
- *Key Assumptions:*
  - Measured effect of 0.8% per 1% drop in voltage applies to average U.S. feeder
  - Average U.S. feeder voltage can be lowered 2.5%
- *Uncertainties:*
  - Need to verify value of key assumptions
- *Recommended Future Work:* Analyze voltage management potential using statistical U.S. feeder prototypes, field test results from smart grid demonstrations

Mechanism I: Reduced Capital Investment for Reserve Generation Capacity Required for Integrating Wind

- Requirements for reserve generation capacity are estimated to increase (2%) as we integrate large amounts of wind generation into grid operations
  - Costs can be avoided by leveraging demand response and distributed generation & storage capabilities
- *Potential* (electric sector)*:*

Sector	Est.	Low	High
1,111 GW Total Generation Capacity @ $1000/kW	2%	1%	3%

- *Basis:* 1,111 GW total U.S. generation capacity in 2030 at $1000/kW
- *Key Assumptions:*
  - 20% RPS goal met with wind power
  - Cost savings are re-invested in cost-effective efficiency/renewables, i.e., at average cost of electricity ($0.088/kWh) *[indirect savings mechanism]*
- *Uncertainties:*
  - Many predict wind penetrations >20%
  - Actual reserve requirements may be higher
  - Averaging over larger balancing areas may lower reserve requirements
- *Recommended Future Work:* Need to better understand ancillary service requirements of renewables (wind & solar)

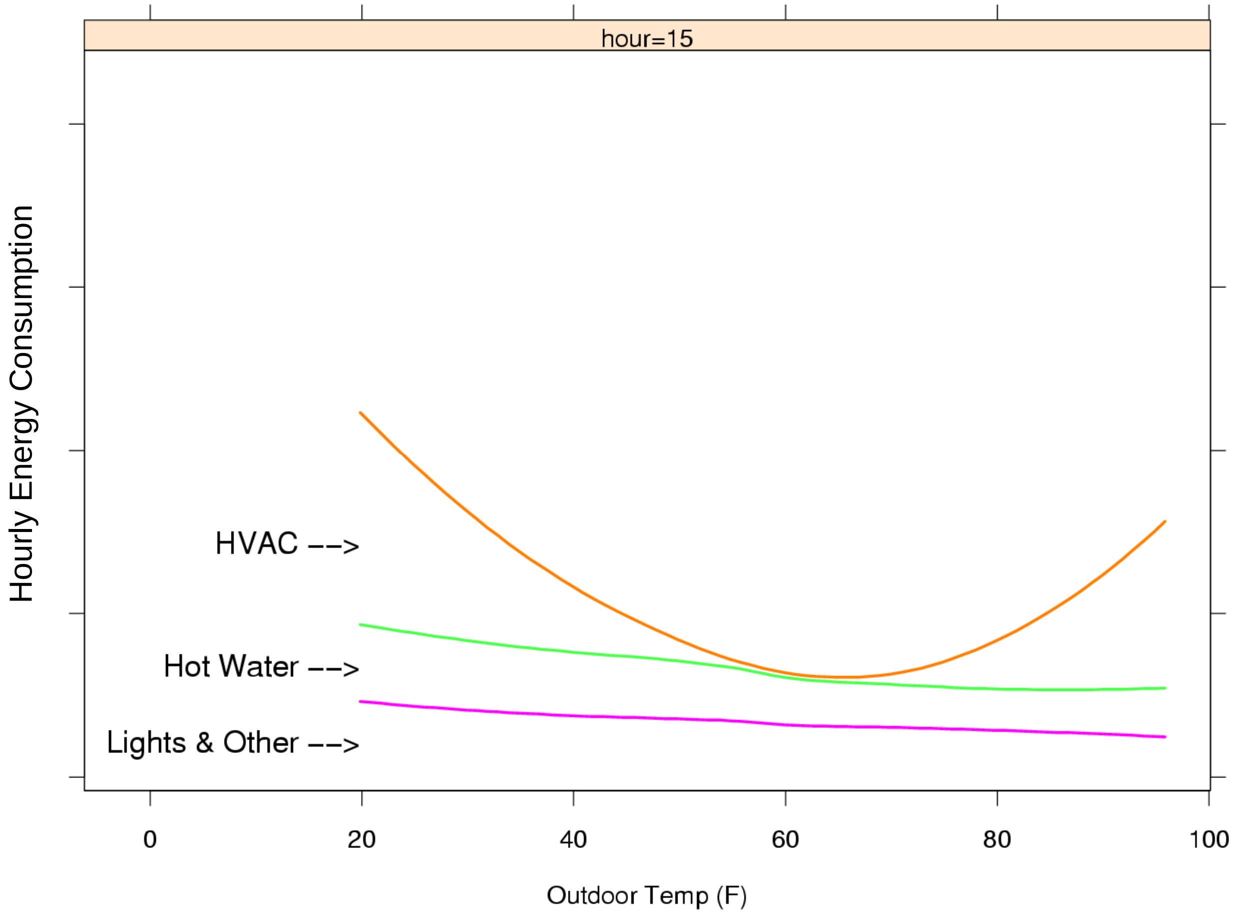
Mechanism F: Support Additional Electric or Plug-In Hybrid Vehicles by Managing Charging

- Electric vehicle penetration will be limited by need to add peak generation capacity if charging is not managed by a smart grid
- *Potential* (light vehicle sector)*:*

Sector	Est.	Low	High
Light Vehicle Transportation (cars, vans, SUVs, light trucks)	3%	2%	5%

- *Basis:* Total light-duty vehicle energy consumption
- *Key Assumptions:*
  - 9% increase in vehicle penetration supported without added capacity (64% vs. 73%)
  - 30% energy efficiency gain (today's vehicle fleet converted to electricity vs. today's marginal power plant mix)
  - 120-volt charging starts at return-to-home times (measured driving sample)
- *Uncertainties:*
  - 120-volt charging may not be practical (cannot complete charging of battery overnight on large vehicles)
  - Savings <u>at 240-volt charging quintuple to 13%</u> (fraction of vehicle energy supportable without smart charging drops from 64% to 32%)
- *Recommended Future Work:* Need to ensure grid can support charging of electric vehicles as they penetrate

A Smart Grid's AMI and Demand Response Infrastructure Can Support Detailed Analysis of Energy Consumption



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Mechanism A: Conservation Effect of Consumer Feedback from Demand Response Programs

- Demand response programs noted to result in reduced energy consumption
  - Presumed from increased energy awareness from feedback on consumption provided by information provided by data from AMI + DR systems (usually web-based)
  - Some additional direct savings, e.g. water heater setbacks
- *Potential* (electric sector)*:*

Sector	Est.	Low	High
Residential	6%	1%	10%
Sm./Med. Commercial	6%	1%	10%

- *Basis:* Total residential and small commercial electricity consumption (large commercial likely already has feedback)
- *Key Assumption:* Average 6% effect measured in consumer feedback technology studies also pertains to smart grid
- *Uncertainties:*
  - Self-selection bias in EE and DR studies
  - Will effects persist? feedback continual or behavior adopted (studies all ~1-year)
- *Recommended Future Work:* Leverage data from smart grid demonstrations to identify and quantify effect

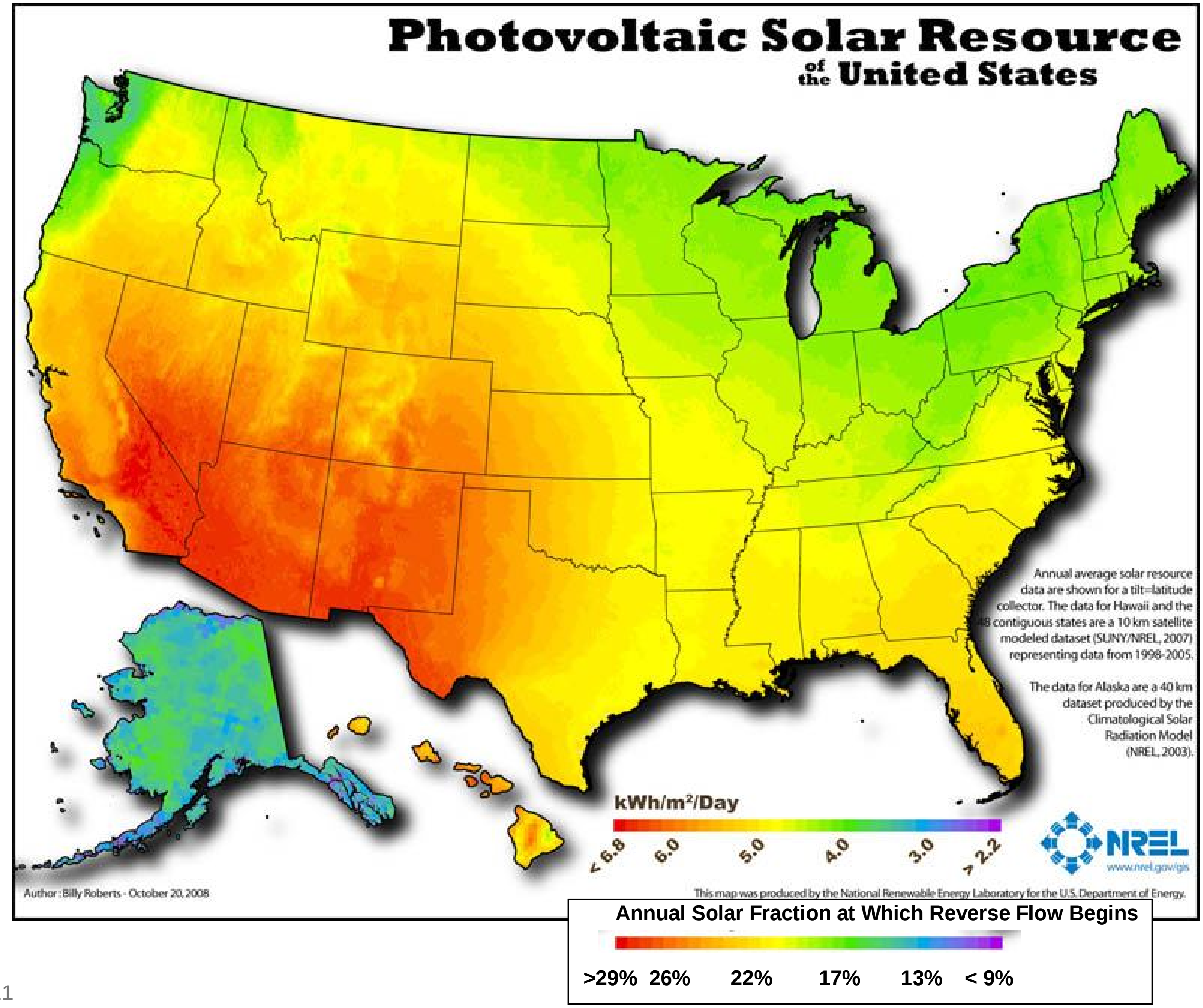
Mechanism C: Smart Grid-Enabled Diagnostics of Energy System Performance

- Provide remote energy system diagnostics using smart grid sensors & communications
  - Disaggregate time-series consumption using AMI & end-use on/off signals from demand response controllers as basis for simple performance diagnostics
  - Also can be used for data mining for savings opportunities, ensuring persistence
- *Potential (electric sector):*

Sector	Est.	Low	High
Residential (Heat Pump & AC)	15%	10%	20%
Sm./Med. Commercial (HVAC + Lighting)	20%	10%	30%

- *Basis:* Residential cooling & heat pump heating; small commercial HVAC electricity & lighting
  - Residential & small/medium commercial building systems are relatively uniform
  - Diagnostics for large commercial buildings unlikely to be provided by smart grid (site-specific set-up required)
- *Key Assumption:* Residential potential similar to commercial
- *Uncertainties:*
  - Will customers allow data to be used? (privacy issues)
  - Will identified problems get fixed? (programmatic mechanism may be required)
- *Recommended Future Work:* Need to develop & test simple, smart-grid-based diagnostics

Annual Solar Energy Fraction in a Residential Neighbor-hood at Which Reverse Power Flow Begins: 17%-28%



- Clear spring/fall days (K_T = 0.75)
- 1 kW residential load at noon
- 1 kW PV array (~6 m^2 @ 17% efficiency) on <u>every</u> house
- Power flow on feeder reverses when PV output exceeds load
  - Voltage control (at head of feeder) becomes ineffective
  - Short circuit protection may become inadequate
  - Smart grid can help

A Smart Grid Will Make a Significant Contribution

- Full implementation of smart grid functionality will provide substantial reductions in U.S. energy consumption and carbon emissions:
  - 9% direct reductions (without electric vehicles)
  - 3% additional direct reductions by supporting additional EVs & PHEVs* at very high penetrations (> 60%) by smart charging
  - 5% indirect reductions from reinvestment of avoided costs for adding extra capacity for regulation and reserves required to support a 25% renewable portfolio standard
- The smart grid may be essential to achieving levels of renewables >> 25%, particularly for customer solar PV**

* electric vehicles and plug-in hybrid electric vehicles

** photovoltaic solar generation by customers

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