Efficient solar photovoltaic deployment

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Why did the gardener plant a light bulb?

He thought he would get a power plant!

Today’s agenda

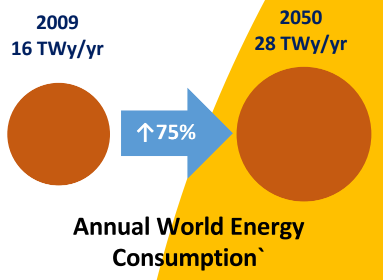
- What is Solar
- Solar installation capacities by country
- Largest solar plants
- Distributed Generation vs. Utility Scale Generation
- Solar + Storage
- How much Solar (GW) do we need to be 100% Solar.
  - Storage required for Solar + Storage
  - Area needed to be 100% solar.
  - Estimated costs
  - Roof top solar
- Transportation with no emissions
- Summary

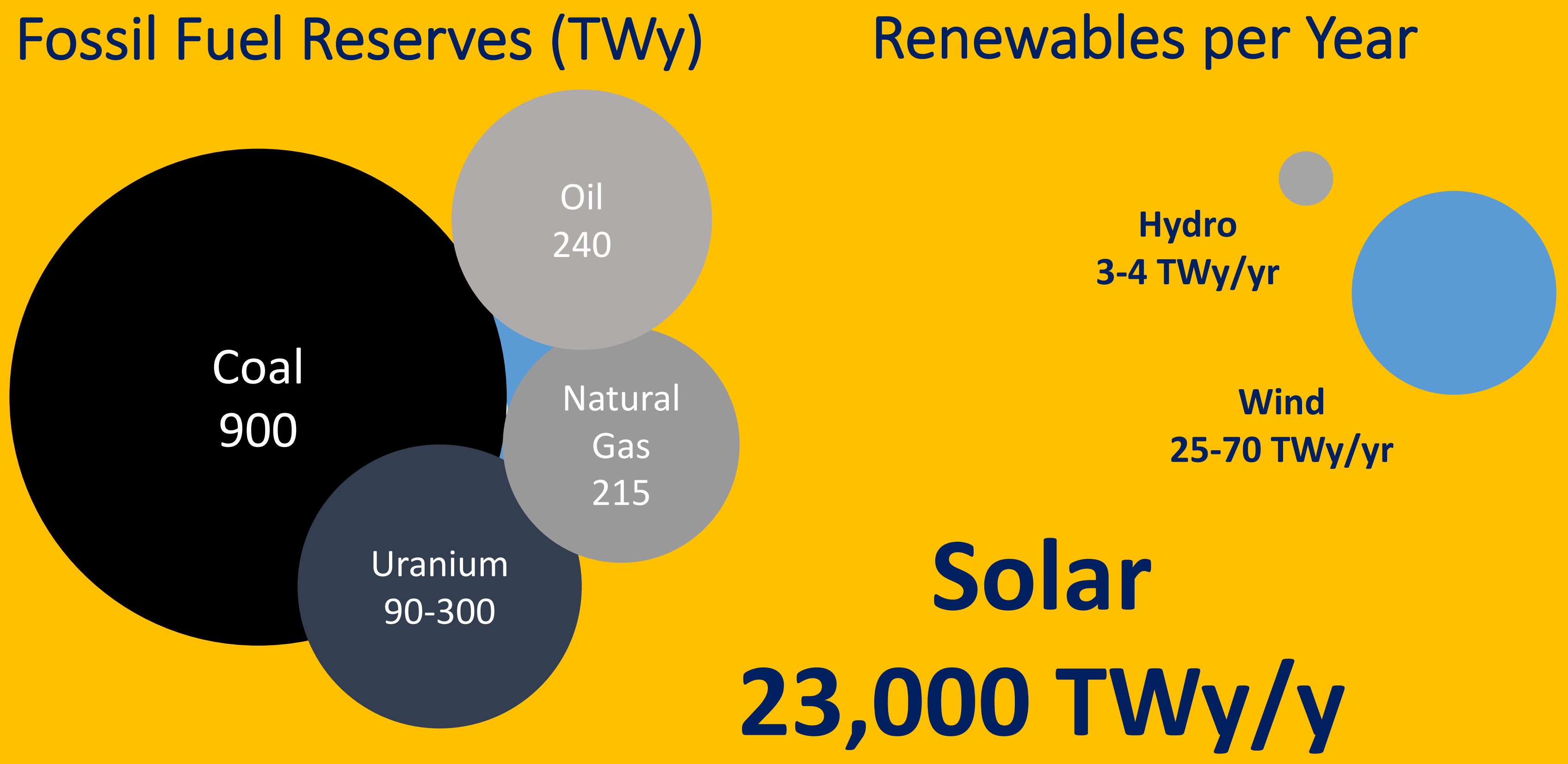
What is solar

- Energy from the Sun.

What is solar?

Solar Resource is Very Abundant …





Source: R. Perez et al, “Renewable Energy Our Solar Future”

What is solar? (continued)

- Photovoltaic : Photon to electron conversion thru semiconductor.

- Questions :
  - Is solar similar to Coal? → Can you place Coal plant on your roof?
  - Is solar similar to Nuclear? → Can you place nuclear plant on your roof?
  - Is solar similar to Natural Gas? → Can you place natural gas plant on your roof?
  - Is solar similar to Hydro? → Can you place Hydro plant on your roof?

Answer “NO”

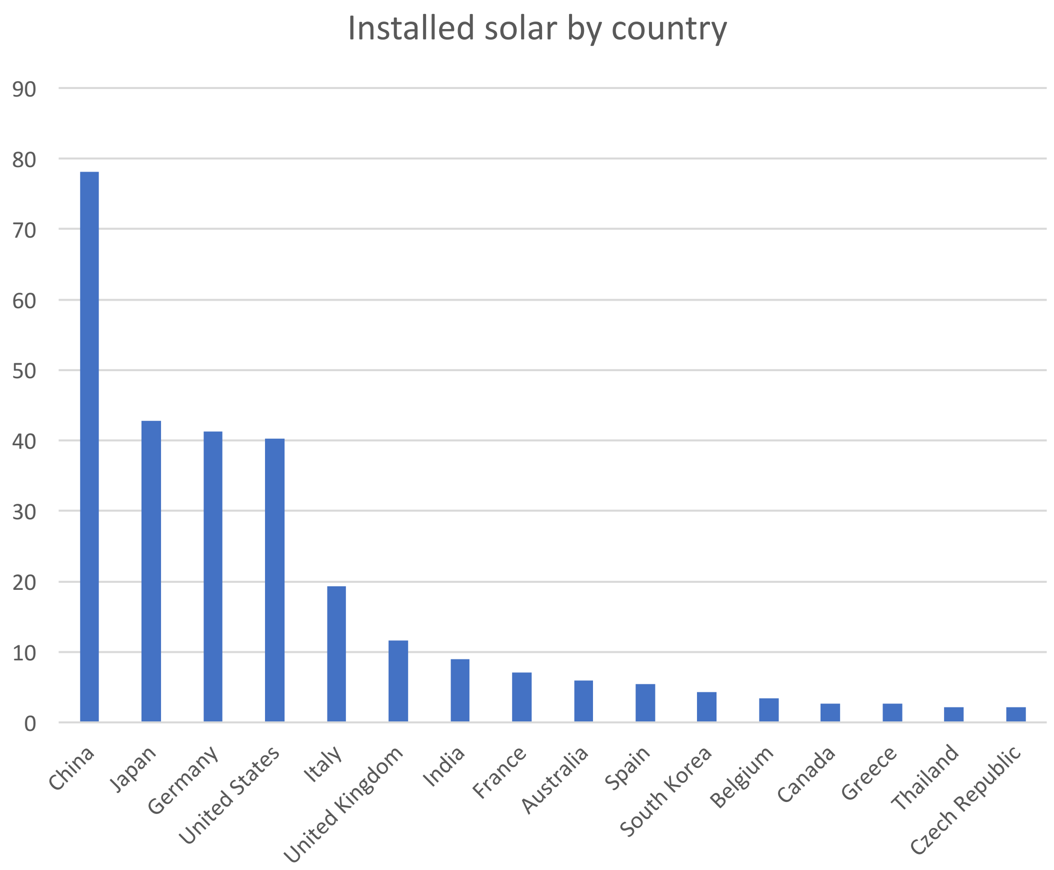
What is solar? (continued)

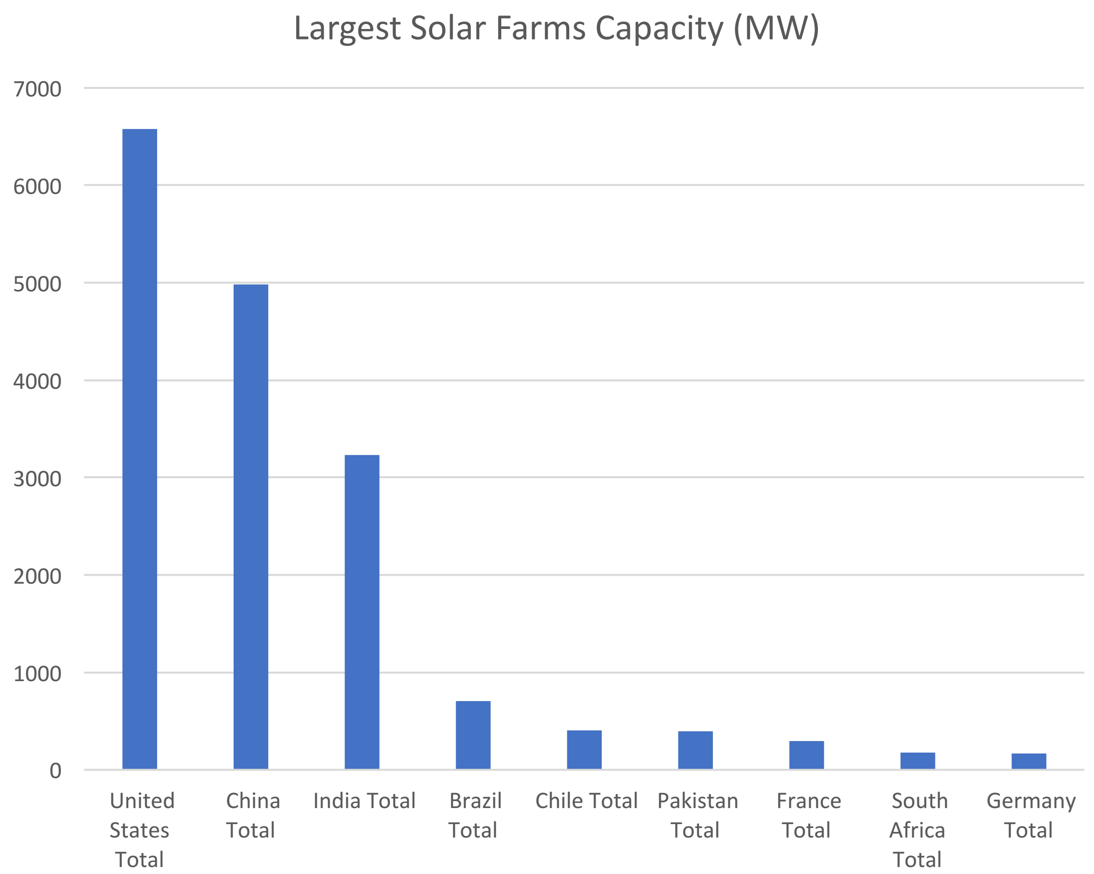
- Conventional generation takes many square miles of land.
- Should solar also take many square miles of land?

Answer “NO”

Solar PV provides the best possible scenario for distributed generation.

Solar by country





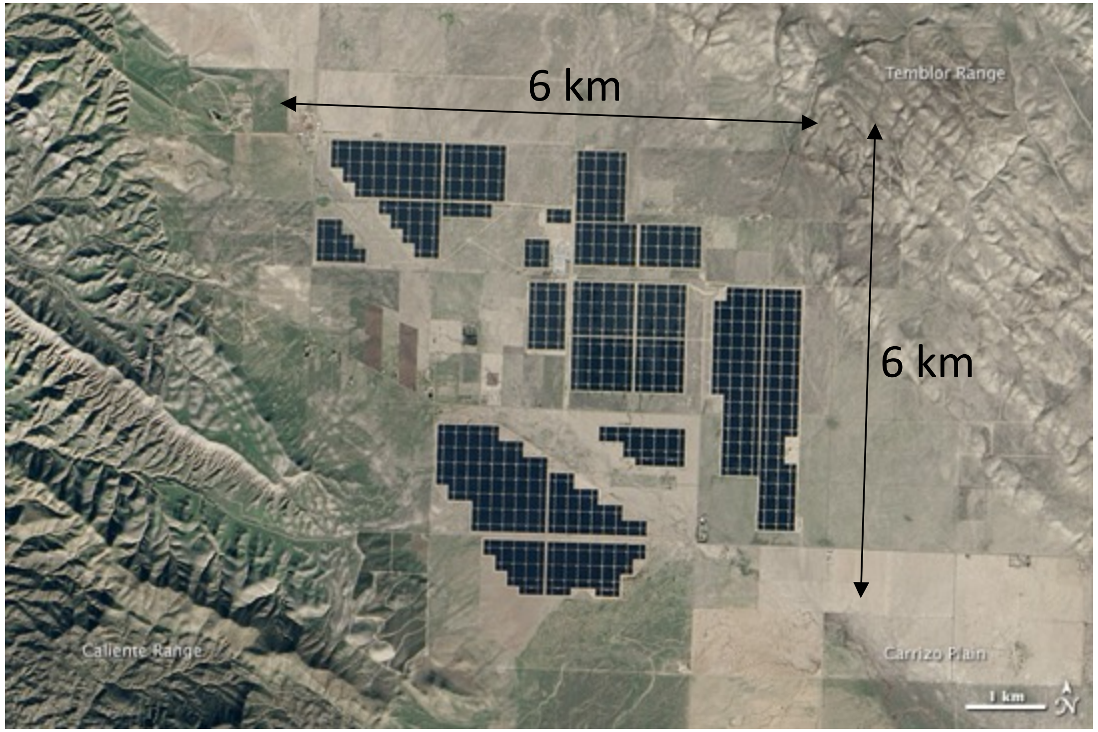
Top 50 largest solar plants – None in Japan & Germany

Japan and Germany have focused on Distributed Generation. Hence no large solar plants.

Distributed vs. Large Scale

Distributed Generation

Utility Scale Generation



Energy Loss

Distributed Solar

- The energy generated on site is directly consumed
- Zero transmission loss.

Large scale Solar

- Energy generated has to go through transmission lines.

Land

Distributed Solar

- No added land cost
- Use existing roof in most cases.
- Use existing land near facility.

Large scale Solar

- Additional land required.
- Land taxes are extra.
- Zoning?
- Animal Habitation loss

Infrastructure

Distributed Solar

- Solar energy generation is at near or same voltage as consumption voltage (120V, 240V, or 480V)
- No need for additional infrastructure.

Large scale Solar

- Energy generated has to be stepped up to distribution/transmission and back down to consumption voltages.
- Added infrastructure for distribution/transmission.

Can solar generate baseline load?

- What is baseline load?
- Day & Night?
- Natural cycles:
  - Winter, summer
  - Rain, snow, cloud and blue sky

- We do need baseline generation.

Jobs

- Local jobs
- Small business participate in roof top solar

- Large scale jobs.
- Mostly >200 employees.

Summary

- Solar is not similar to coal, nuclear, natural gas and hydro.
- Solar provides unique opportunity in distributed generation by using existing resources (land and infrastructure).

Utility Scale vs. Distributed generation Solar - Demystified

	Utility Scale	Distributed generation
Energy Loss	30% to 40% losses from transmission and voltage conversions.	In most cases less than 5% loss.
Land	Remote Land used	Existing roof tops used
Company type	Financing companies.	Mostly electrical and general contractors.
Jobs	Most jobs will be in the legal, adminstrative and regulation since large number of legal documents have to be reviewed for long term contracts.	Significant jobs are created because multitude of roof tops are present. Most jobs will be engineering and skilled trades.
Infrastructure	Will need new infrastructure by way of sub station at utility connection point.	no new infrastructure.
Manufacturing	Single purchaser (large scale) means manufacturing companies controlled by finacing companies who obtain PPAs for utility scale projects.	Fragmented purchasing because many contractors. Will need a distributor to buffer the manufacturing supply.
Complexity	The complexity is in the PPA and with future pricing.	Complexity is in metering and utility management of the billing.
Solar Photovoltaics have created a brand new utility scale sector in distributed generation		

Why do transformers hum?

They don’t know the words!

Next steps for solar photovoltaic

- Solar cannot be generated at night.
- Solar cannot be generated during snow/rain.
- Solar generation is limited when sun hours are short (winter).

Solar + storage

- Solar is abundant in summer.
- Need ways to capture the abundance (storage).
- Storage has to be:
    - Environmentally friendly.
        - Land use
    - Sufficient Life (Cycles to failure)
    - Low leakage.
    - Recyclable.
    - Cheap.
    - Safe.

Solar + storage

- Today solar + storage is possible in remote areas where new power lines have to be constructed.

- Price of solar + storage is coming down and is becoming feasible in most international markets where new transmission lines are needed.

Let’s bring it home to Minnesota

- What will solar + storage look like in Minnesota?

- Hope we can work together to see this to reality!!

Present Generation Capacity in MN

Minnesota Electricity Profile 2016**

Table 1. 2016 Summary statistics (Minnesota)	
Item	**Value**
Primary energy source	
Net summer capacity (megawatts)	**16,012**
Electric utilities	11,617
IPP & CHP	4,395
Net generation (megawatthours)	**59,478,753**
Electric utilities	47,984,837
IPP & CHP	11,493,915
Emissions	
Sulfur dioxide (short tons)	26,693
Nitrogen oxide (short tons)	27,953
Carbon dioxide (thousand metric tons)	29,644
Sulfur dioxide (lbs/MWh)	0.9
Nitrogen oxide (lbs/MWh)	0.9
Carbon dioxide (lbs/MWh)	1,096
Total retail sales (megawatthours)	**66,546,492**
Full service provider sales	66,546,492
Energy-only provider sales	
Direct use (megawatthours)	**1,240,242**
Average retail price (cents/kWh)	**9.99**

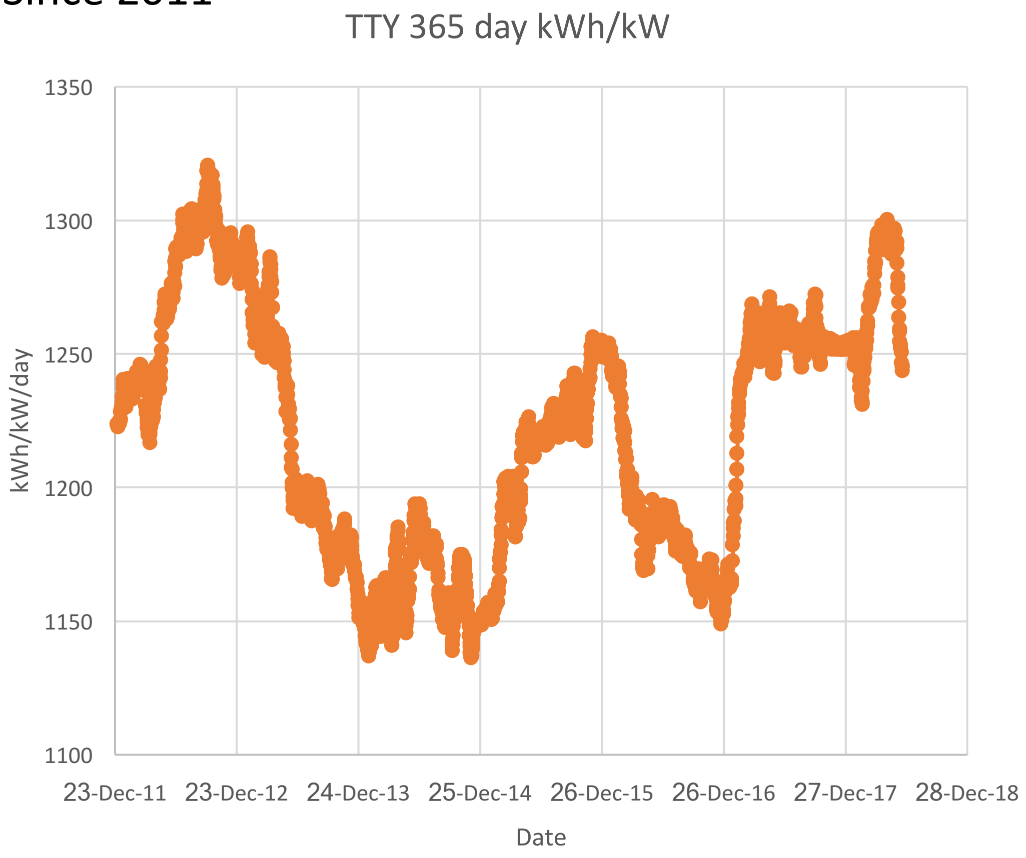
The utilities generate roughly **11.6 GW**.

** From EIA: https://www.eia.gov/electricity/state/minnesota/

Capacity Factor of Solar in MN

Capacity factor is the amount of energy generated by the Sun in a given year.

Minneapolis Convention Center 600 kW Solar
Since 2011



- A solar system in Minnesota is widely accepted to produce between 1150 and 1300 kWh per kW per year.

What is the capacity factor in Minnesota

- Capacity factor is defined as the kWh per hour generation.
  - One year has 8760 hours.
  - The solar generation in Minnesota will have a capacity factor of

$$1250 \div 8760 = 14.3\ \%$$

How much solar will be needed

- If we have a capacity of 14.3 %, to offset 12 GW of generation, the solar needed would be
  - 12 GW ÷ 14.3% = 84 GW of Solar

How much floor space is needed

- 1 MW requires 3 acres.
  - Hence 84 GW will require 260,000 acres or 400 sq. miles
  - Minneapolis / St. Paul is 3000 sq. miles hence roughly 1/7th the area of MSP.
- MSP has roughly 1.4 million homes**.
  - If all homes have solar it can produce the required energy to offset, charge and load the baseload capacity.

**https://www2.census.gov/programs-surveys/ahs/2013/factsheets/ahs13-13_Minneapolis.pdf

How much storage

- Since solar is not going to be present in the night time, cloudy times and snow times, storage is needed to back up the solar.

- The battery needed is estimated at 2.5 times solar generation, hence,
  - 84 x 2.5 = 210 GWh

Total estimated cost

- 84 GW @ \$1.5/W → \$126 B
- Storage @ \$0.2/Wh → \$42 B

- Therefore for a total cost of nearly \$200 B, the present utility generation capacity can be offset using solar + Storage.

Why is wind power popular?

Because it has a lot of fans!

What next

- Residential / Commercial / Building Energy was estimated at 12 GW.

- Transportation is another form of “Brown” energy.
- How can we reduce transportation’s “Brown” energy?

Transportation

- Buildings and homes are about 30%.
- Nearly 40% of emissions come from transportation.
- Heating and cooling is another 30%.
- To offset transportation, heating and cooling the amount of renewable generation has to be 3 times that of Building and homes.

Can clean energy be used for transport?

Objectives

1. Understand how automobiles contribute to our carbon foot print.
   a. Modes of transportation
   b. Average miles traveled.
   c. IC Engine CO_2 emissions.
   d. CO_2 from transportation.
2. Understand how Electric vehicle can reduce carbon foot print
   a. EV emissions from conventional charging.
   b. EV vs. IC Engine emissions
   c. Hybrid vehicles.
   d. Solar PV for charging

Conversion terms

- 1 kWh = 860 kCal = 860,000 Calories
- 0.0007 kWh = 600 Cal
  - When you work out 600 calories its equivalent to using a 10W LED bulb for 2.5 minutes
- 1 KWh = 3413 Btu
- 0.0007 kWh = 2.3 Btu

Some Energy conversions

- 1 gallon gasoline = 36 kWh
- 1 lb of coal = 4.4 kWh
- 1 lb of Uranium = 1.02×10^{7} kWh
- 1 candy bar = 0.28 kWh
- 1 AA Battery = 0.0003 kWh

http://www.phy.syr.edu/courses/modules/ENERGY/ENERGY_POLICY/tables.html

CO_2 Emissions

- Coal (1 lbs)

  CO_2 emission=2.1 lbs/kWh

  =0.96 kg/kWh

- Gasoline (1 Gal)

  CO_2 emission = 8.8kg/gal

- Diesel (1 Gal)

  CO_2 emission = 10.1kg/gal

1 lb CO_2 = 0.3 lbs of C

Tree conversion.

- Tree conversion of CO2.
  - 6 CO_2 + 6 H_2O + sunlight ---> $C_6H_{12}O_6$ + 6 O_2
  - $C_6H_{12}O_6$ is sugar (at mass, H=1,C=12,O=16)
  - 45% of sugar is C

- 100 lbs of a tree, ~45 lbs is from Carbon and the rest is Water and residual minerals.

Tree to Fossil fuel rate

- A tree weighs about 2 tons to 10 tons.
- An average life of a tree is about 75 years.

  6 tons ÷ 75 years = 80 kg of tree per year.

  80kg of tree = 36 kg of Carbon

1 tree absorbs 36kg of carbon each year.

Tree to Fossil fuel rate

- Gasoline = 8.8 kg/gal of CO_2
  = 2.5 kg/gal of Carbon

  1 Gallon Gasoline = 2.5 kg of Carbon

Therefore from Carbon

  36 kg for 1 tree = 15 gallons of gasoline

Tree to Fossil fuel rate → Transportation

- Americans drive ~ 20,000 mpy @ average of 25 mpg

- And use about 800 gal per year

Therefore

800 gal ÷ 15 gallons/tree = <u>54 trees/person/yr</u>

Fossil Fuel

- Burning fossil fuel at high rates, we are putting more carbon into the atmosphere than the ability to convert.

Conventional & Clean Energy

- Conventional:
  - Coal (~ 2 lbs of CO_2 per kWh)
  - Nuclear
  - Hydro
  - LP:
    - Gasoline (8.8 kg of CO_2 per kWh)
    - Diesel (10.1 kg of CO_2 per kWh)
  - Natural Gas (~1.22 lbs of CO_2 per kWh)
- Clean
  - Hydro (If no loss from flooding)
  - Solar (200W panel works for > 2 years)
  - Wind

Modes of transportation

• Walking	✓
• Boats	✓
• Animal assisted cart	✓
• Steam engine – train.	X
• Ships – coal powered.	X
• Automobiles – cars, 2and 3 wheelers.	X
• Aircrafts – commercial, civil, military	X
• Rockets	✓

Miles per year per person

- America
  - Automobile – 20,000 m/yr
  - Aircraft – 2,000 m/yr
  - Train – 0/yr

7300 kg of CO2

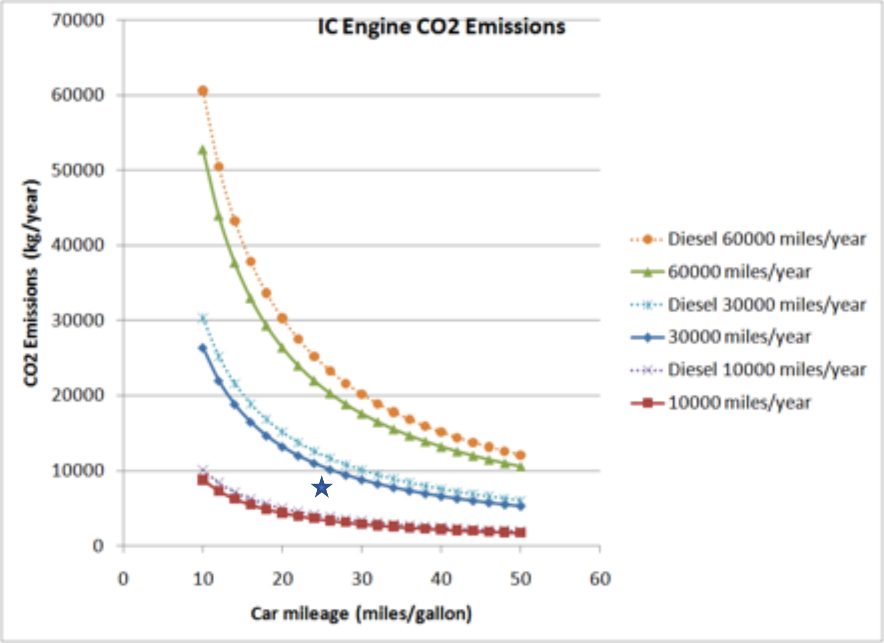
- Europe / Japan
  - Automobile – 5000 m/yr
  - Aircraft – 5 m/yr
  - Train – 1000 m/yr

2500 kg of CO2

- Rest of the world
  - Automobile – 300 m/yr
  - Aircraft – 5 m/yr
  - Train – 5 m/yr

120 kg of CO2

IC Engine CO_2 Emissions



- 20,000 mpy
- 25 mpg vehicle

  = 800 gallons/year
- CO_2 emissions

  = 800 * 8.8 kg/gal

  = 7.3 tons/ year of CO_2

Assumptions:

CO2 emission of gasoline per gallon	8.8 kg/gal
CO2 emission of Diesel per gallon	10.1 kg/gal
Coal CO2 emission	2.117 lbs/kWh
Coal CO2 emission	0.962 kg/kWh
Percent of Coal generated power	60% in Minnesota
Line energy emission	0.577 kg/kWh

CO2 emission from transport – IC Engine

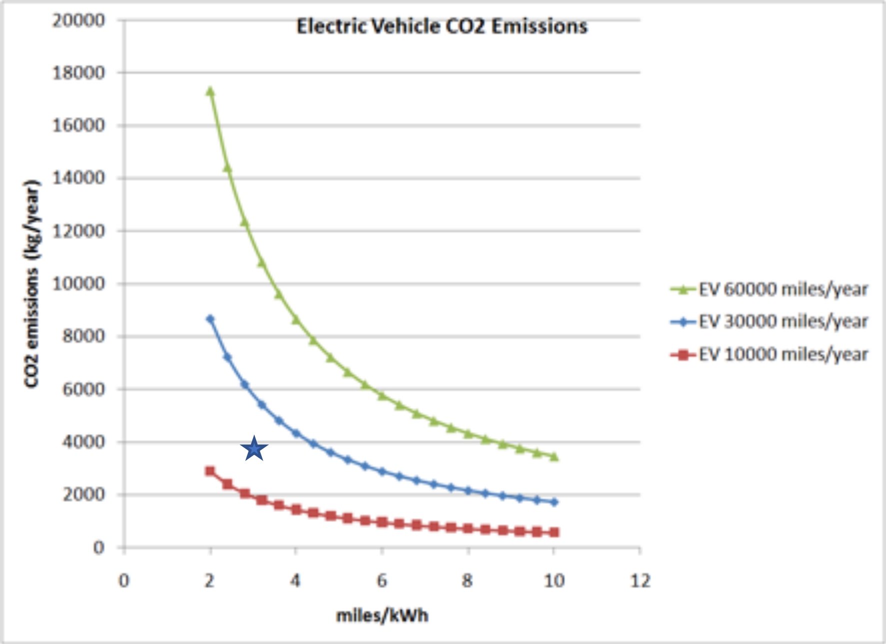
America

- 7300 kg CO2 = 2100 kg of Carbon
- 36 kg of Carbon in 1 tree per year.
- 2100kg/36kg = 54 trees per person/year

- 300 Million people in the US
- 54 trees/person/year
- Will need 16 Billion trees/year.
- Estimates are that US has about 150Million acres of forest and 300 tree/acre.

  = 45 Billion trees in the US

Electric vehicle CO2 Emissions - EV



Assumptions:

CO2 emission of gasolene per gallon	8.8 kg/gal
CO2 emission of Diesel per gallon	10.1 kg/gal
Coal CO2 emission	2.117 lbs/kWh
Coal CO2 emission	0.962 kg/kWh
Percent of Coal generated power	60% in Minnesota
Line energy emission	0.577 kg/kWh

- 20,000 mpy
- 3 miles/kWh

  = 6700 kWh/year
- CO2 emissions

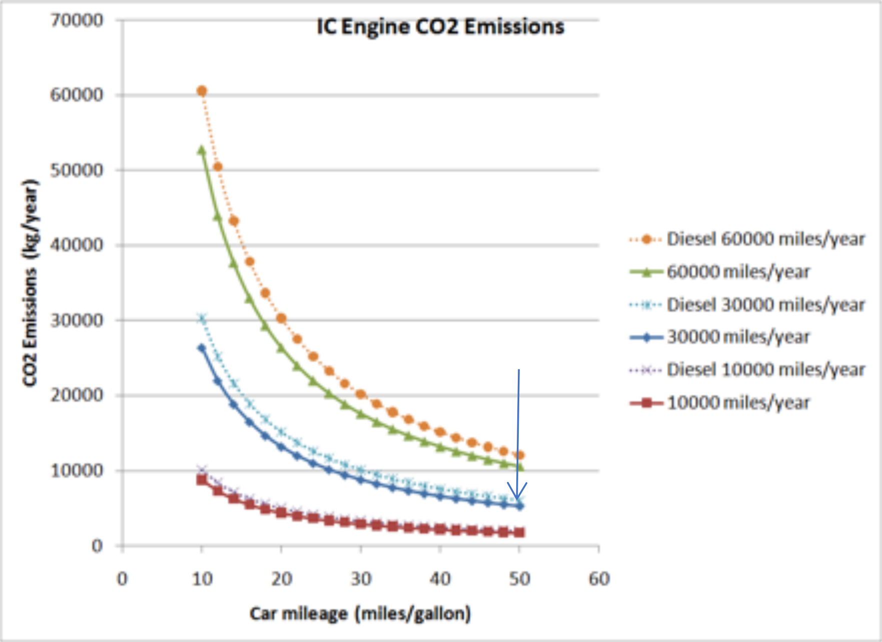
  = 6700 * 0.96 kg/kWh * 60% coal in MN

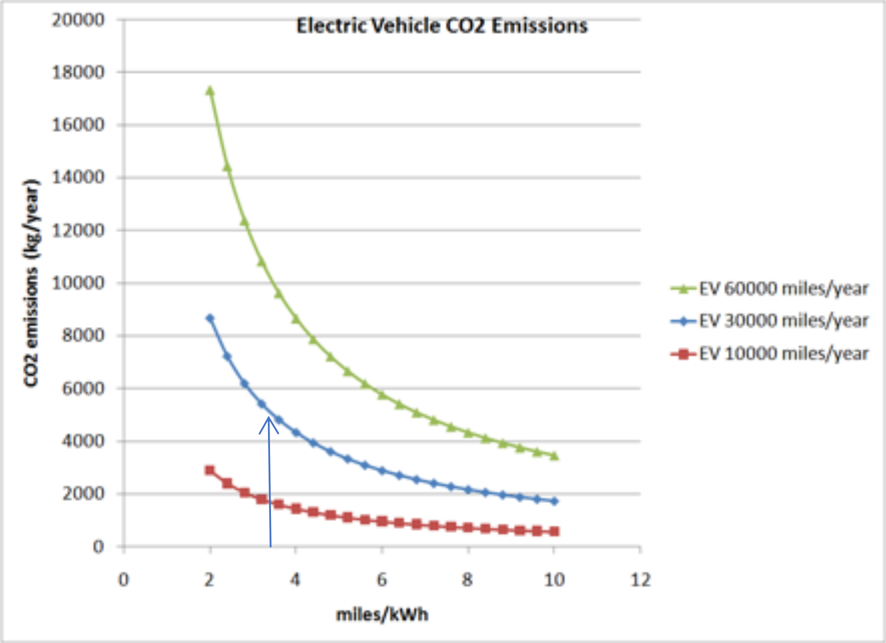
  = 3.9 tons/ year

Compared to Gasoline → 7.3 tons/yr for IC Engines

EV are about half the emissions of IC Engines

IC Engine and Electric vehicle CO2 Emissions





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EV vs. IC Engine

Example: 30,000 m/yr

IC Engine (50 mpg) CO2 emissions = 5280 kg/yr

EV (3.4 m/kWh) CO2 emissions = 5111 kg/yr

IC Engine with 50 mpg = 3.4 mile/kWh
Unless charged by solar

Energy generated from Solar PV installation & miles/year for EV

kW of Solar Installation	Energy from Solar/year (kWh)	3.2 miles/kWh	
		miles/yr	miles/day
1	1224	3917	11
2	2448	7835	21
3	3673	11752	32
4	4897	15670	43
5	6121	19587	54
6	7345	23505	64
7	8569	27422	75
8	9794	31340	86
9	11018	35257	97
10	12242	39175	107

Example: If one drives 15,000 miles/year, a 4kW solar system will offset all fuel requirements.

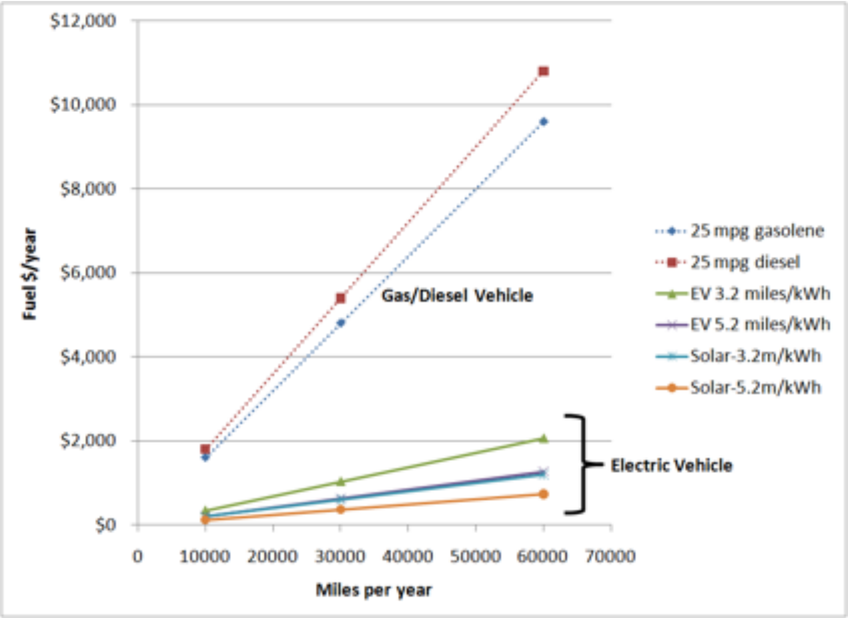
Cost for solar today

	Traditional roof top Solar	Units
System size	4000	W
Installation cost	$3/W	$/W
System cost	$12,000	$
Rebates	$3600	$
Out of pocket cost	**$8,400**	$
Energy per year	5000	kWh
Annual $ savings	$650	$/yr
Utility rate	0.13	$/kWh
Life of system	25	Years
Miles/kWh	3.2	
$/Mile	$0.040	$

Miles per year	16000
Miles per Gallon	30
$/Gallon	$2.50
$/Mile	$0.083

Solar can reduce cost and emissions.

Cost for Solar as fuel for EV



- Solar cost can be lower for driving.
- EV typically have lower maintenance cost.
- Charging is a big issue for an all electric vehicle.

Summary

1. EV gives about 3 miles per kWh.
2. Emissions
    1. I C Engine auto with 50 mpg = EV with 3miles/kWh (with conventional chg).
    2. Solar PV can be used as clean energy charging.

Summary – Take away from today

- Most efficient deployment of solar is in distributed generation.
- Using distributed generation a large portion of Minnesota's energy can be converted to solar + storage.

  → Need about $200 B
- Transportation can also be converted to solar.
- Operational cost for solar is significantly lower than IC engines.

Contact

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SolarPod™

Mouli Engineering Inc.

The Environment
is not a
spectator sport

Using GIS-based methods and lidar data to estimate rooftop solar technical potential in US cities

Robert Margolis1 , Pieter Gagnon, Jennifer Melius, Caleb Phillips and Ryan Elmore
Strategic Energy Analysis Center, National Renewable Energy Laboratory, 901 D Street, SW Suite 930, Washington, DC 20024, United States of America

- Rooftop PV's ability to meet estimated electricity demand varies widely—
  - 16% of demand (in Washington, DC) to
  - 88% (in Mission Viejo, CA)
- Assumptions important to results
  - 20% vs. 16% can change PV generation by 25%
  - Using only rooftops and not including any adjacent land (Backyard, etc.)
- Actual generation from PV in urban areas also could exceed these estimates if systems were installed on less suitable roof area, PV were mounted on canopies over open spaces such as parking lots, or PV were integrated into building facades