A Reasoned Analysis for a New Distributed-Generation Pricing Mechanism for Michigan Regulated Electric Utilities

Preliminary Study

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Outline

1. **Introduction**
2. Foundations
3. Modeling overview
4. Onsite-usage analysis
5. Cost-of-Service implications of DG study results
6. Economic & payback analysis

Legislative Directives to the Michigan Public Service Commission

PA 341 Sec. 6 (a) (13)

…**the commission** shall conduct a study on an appropriate tariff reflecting an equitable cost of service for utility revenue requirements for customers who participate in a net metering program or distributed generation program under the clean and renewable energy and waste reduction act…

…**the commission** shall approve such a tariff for inclusion in the rates of all customers participating in a net metering or distributed generation program…

Hierarchy of Legislative Directives

The commission shall conduct a study:

- on an appropriate tariff
- reflecting an equitable cost of service
- for utility revenue requirements

for customers who participate in a net metering program or distributed generation program

DG Pricing Mechanism

"tariff"

Primary Objective

To develop a new approach to replace Net Energy Metering*

for renewable generation under 150 kW, and for methane digesters up to 550 kW

- That allows for traditional cost-of-service methods to allocate costs, and thus determine a fair cost-of-service
- That has billing determinants that strongly connect to actual grid usage, and thus provides accurate and transparent price signals:
  - Inducing optimal DG system operations
  - That fairly monetizes the value of customer participation in **demand response**, **load control**, and **energy efficiency** actions, and thus equitably contributes toward the purchase of advanced technologies that allow such activities
- Retains DG as a reasonable/economic option for customers

* Subject to PA 342, Sec. 183

Secondary Objectives

- To determine if it is necessary to create **specific DG rate classes** for "solar, solar/battery, or other renewable energy systems" for allocating costs in a COSS
- To determine a **valuation method** for customer-sited generation that is injected into the grid (excess generation)
- To determine whether **credit for generation-capacity** should be reflected:
  - ***on a class basis*** [i.e. as an offset to coincident demand (inflow) in the COSS]; or
  - ***on an individual customer basis***, [i.e. as bill credits for DG capacity available to the grid (per kWh or kW credit)]

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Distributed Generation (DG) Program Regulatory Principles

All DG pricing mechanisms are variations of three foundational approaches:

- **(1) Grid-based balancing service**
- **(2) Retail customer as Small Power Producer (SPP)**
- **(3) Actual power inflows and outflows as billing determinants**

DG Mechanisms

- **Balancing services**
  - **True net-metering** operates as an uncompensated (free) kWh balancing service [grid as battery]
  - **Modified net-metering** is a billing or pricing-period balancing-service in which net excess generation is converted to a $ credit (applied to future monthly bills)
- **Retail customer as Small Power Producer** (generation is separately metered)
  - **[True feed-in tariff]** Generation is interconnected upstream of the utility billing meter
  - **[Buy-all Sell-all]** Generation is interconnected downstream of the utility billing meter (at the customer's service panel)
- **Inflows and outflows as billing determinants**
  - **[Inflow & Outflow Mechanism]** Power inflows are retail purchases, power outflows credited as if generated by a SPP

Net Energy Metering Pricing Model

Uses net of [Inflow – Outflow] to calculate the customer bill:

$$\boldsymbol{Customer\ Charge + (kWh)_{[(Inflow-Outflow)+CF]} \times \left(\frac{\$}{kWh}\right)_{Full\ Retail\ Rate}} \quad \boldsymbol{If\ (I-O) + CarryForward > 0}$$

or = $\boldsymbol{Customer\ Charge}$ $\quad \boldsymbol{If\ (I-O) + CarryForward \leq 0}$

Buy-all Sell-all Pricing Model

Uses Consumption and Generation to calculate the customer bill:

$$Customer\ Charge + (kWh)_{Consumption} \times \left(\frac{\$}{kWh}\right)_{Full\ Retail\ Rate} - [(kWh)_{Generation} \times \left(\frac{\$}{kWh}\right)_{Value\ of\ Energy} - Capacity\ Credit_{Generation}$$

Based on Nameplate Capacity:
e.g.
$ELCC \times Capacity_{Nameplate}$

Traditional DG Pricing Mechanisms were Designed to Promote Market Adoption of Nascent Renewable Technologies

- **Net Energy Metering** (NEM): *understates* cost-of-service
  - By definition true NEM applies the standard retail-rate to a customer's **net purchases** and that precludes customer bills from reflecting COS
- **Buy-all Sell-all** (BASA): *overstates* COS
  - Uses billing determinants that conflict with actual power flows
  - High "feed in" or "value of solar" credits needed to provide economic payback

DG Pricing-Mechanism Conundrum

Billing determinants that deviate substantially from the physical service provided make it exceptionally difficult to:

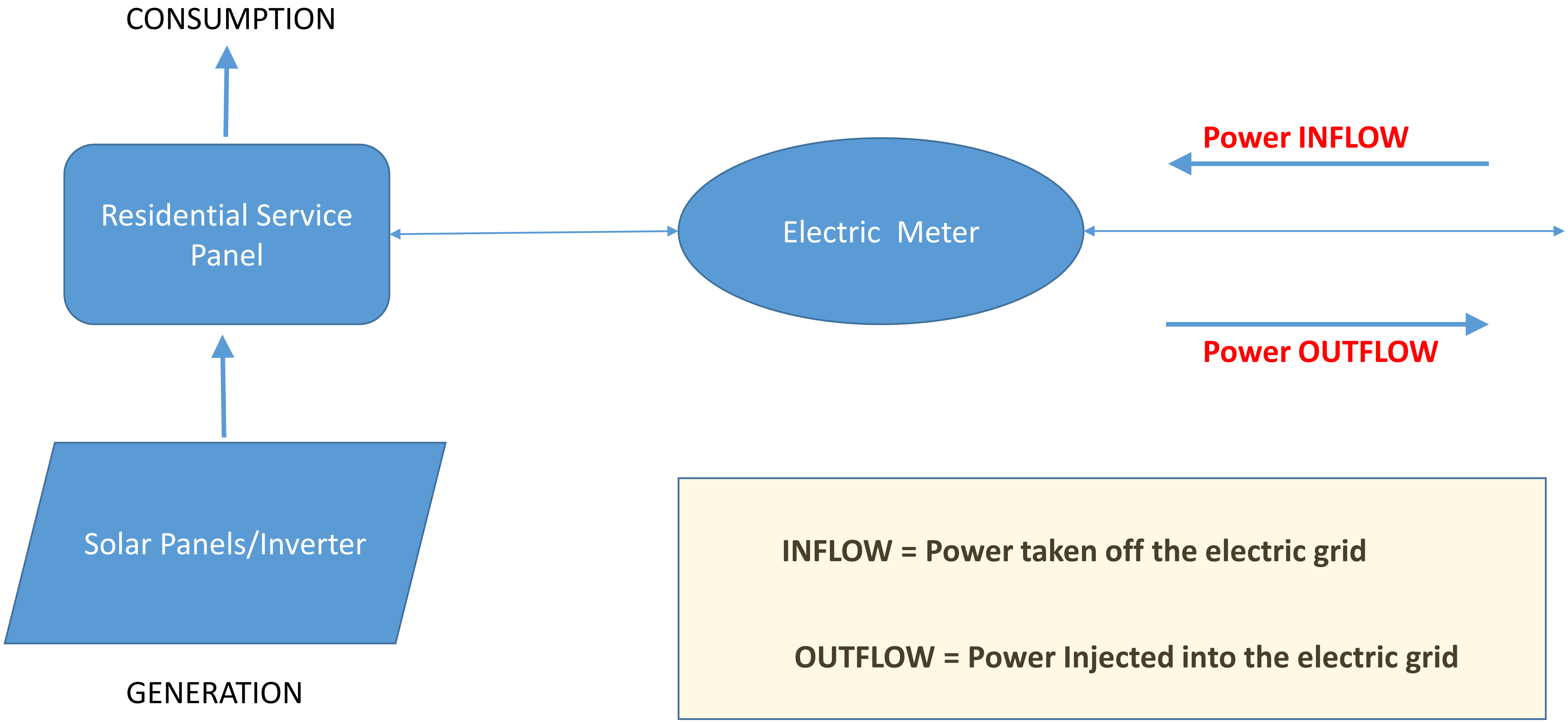
(1) recover a "fair" cost of service; and
(2) induce efficient operational and economic behavior

Core Issue:

Solution - Inflow & Outflow Mechanism

- **Supports traditional cost causation analysis**
  - Easiest method to implement *cost-of-service* based rates
  - Allows for dynamic pricing, dynamic credits, value of energy or avoided-cost credits, and demand charges (distribution and power supply)
- **Customer bills are highly correlated with actual power flows** at the customer’s interconnection with the distribution grid
  - Can send clear and accurate pricing signals to customers
- **Flexible platform is “future proof”** with respect to changing DG technologies and regulatory objectives

What is INFLOW and OUTFLOW?



Inflow & Outflow Pricing Model

[Simple commodity based rate-design]

Uses Inflow and Outflow to calculate the customer bill:

$$\boldsymbol{Customer\ Charge} + (\boldsymbol{kWh})_{\boldsymbol{Inflow}} \times \left(\frac{\$}{\boldsymbol{kWh}}\right)_{\boldsymbol{Full\ Retail\ Rate}} - [(\boldsymbol{kWh})_{\boldsymbol{Outflow}} \times \left(\frac{\$}{\boldsymbol{kWh}}\right)_{\boldsymbol{Value\ of\ Energy\ \&\ Capacity}}$$

Starting Point: Same Retail Rate as Full Requirements Customers

Inflow & Outflow Pricing Model

[Commodity and demand based rate-design]

Uses Inflow and Outflow to calculate the customer bill:

$$\boldsymbol{Customer\ Charge} + (kWh)_{Inflow} \times \left(\frac{\$}{kWh}\right)_{Distribution\ \&\ Power\ Supply} + (kW)_{Inflow} \times \left(\frac{\$}{kW}\right)_{Distribution\ \&\ Power\ Supply}$$

$$- [(kWh)_{Outflow} \times \left(\frac{\$}{kWh}\right)_{Value\ of\ Energy} - Capacity\ Credit_{Outflow}$$

Based on Outflow, not Nameplate Capacity:

e.g.

$$ELCC \times Capacity_{Nameplate} \times Outflow_{Capacity\ Factor}$$

I & O Mechanism Requirements

- **Billing meter must be capable of measuring power flows in both directions**
  - Extensive smart-meter data allows for progressively more accurate COSS allocators in future general rate proceedings
  - Reasonable to base implementation on net-metered hourly demand [i.e. net inflow or net outflow]

- Ideal implementation based on independent calculation of **integrated** inflows and **integrated** outflows
  - On an instantaneous basis, there is only a power inflow or outflow
  - In any given hour a customer can have both inflows and outflows
  - Not the same as net-metered hourly demand
  - Consideration for future fine-tuning of I&O mechanism

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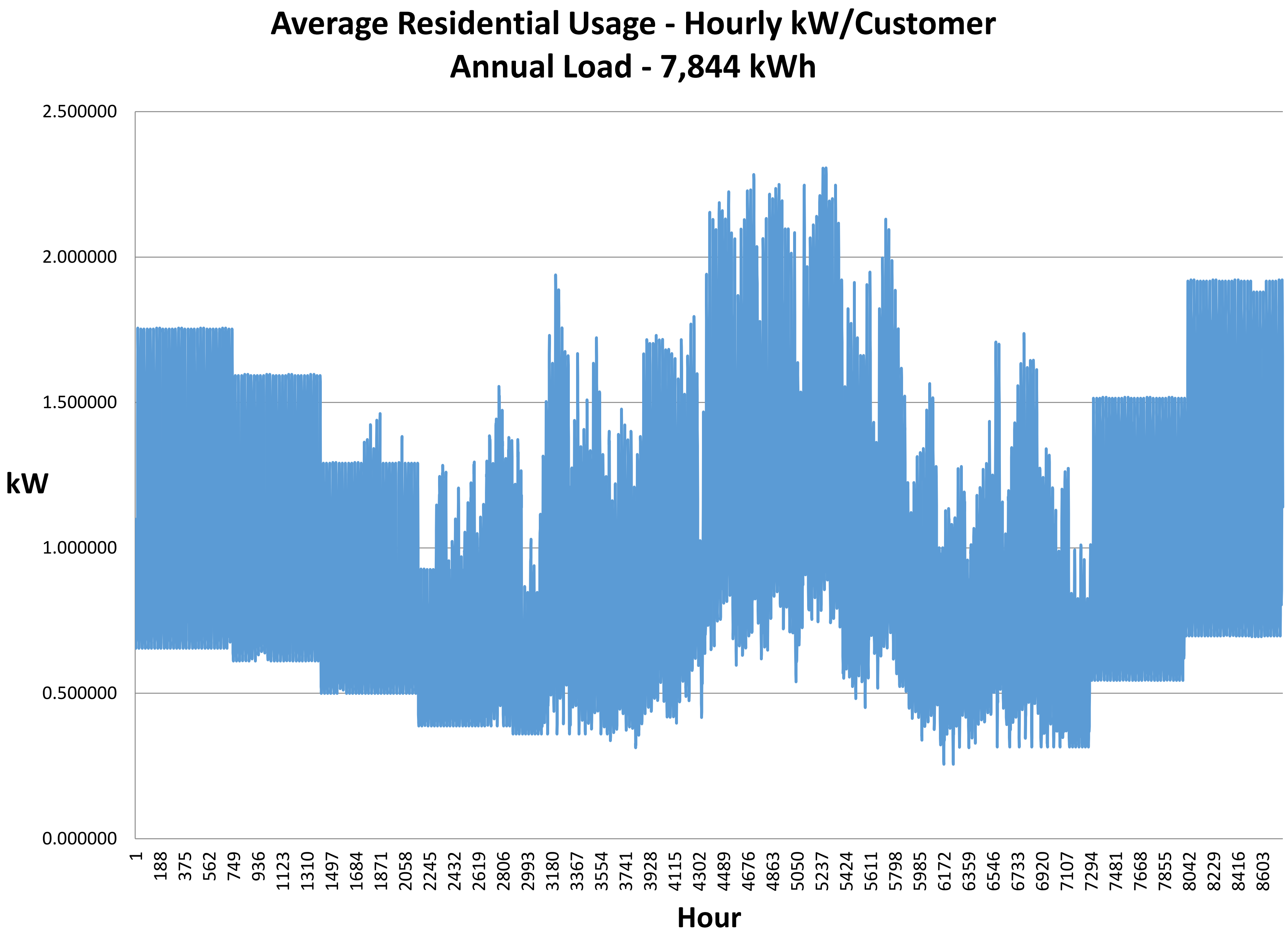
Model Structure

- Excel Model (hourly)
- Model input – residential consumption & solar PV generation

DOE/NREL System Advisor Model (SAM)
Residential Hourly Load Distribution
[Lansing Capital City Airport TMY3]

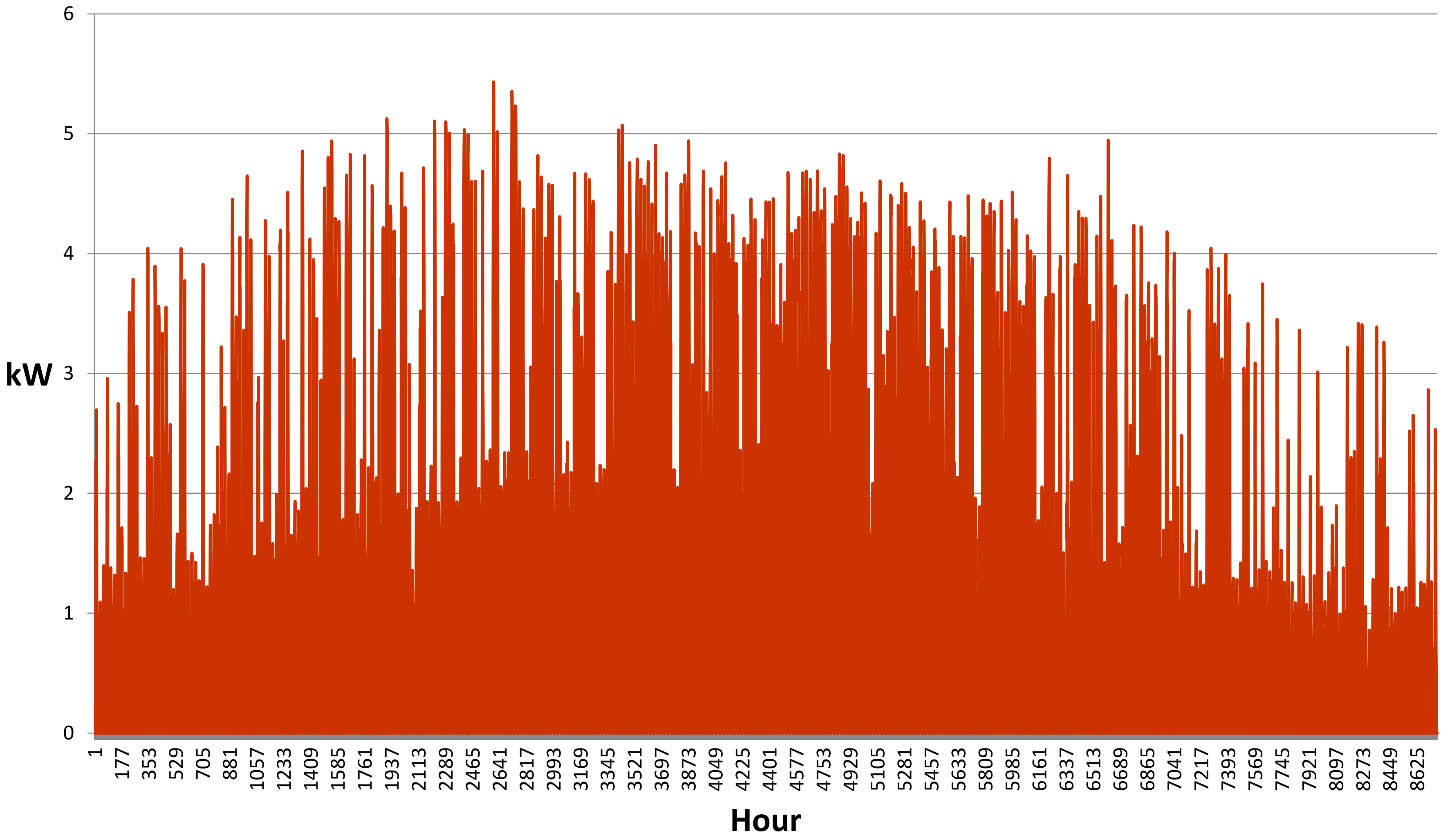
NREL PV watts Model
(8760 hour) Solar Output kW (AC)
Fixed Tilt @ 20deg, Lansing MI

- SAM output calibrated to Consumers Energy's projected 2016 test-year residential annual sales level of 7,844 kWh [U-17990]
- Monthly sales distribution calibrated to match CE's 3-year average residential 4CP (best match uses historical 2010 residential monthly sales distribution)
- **Model Output - power inflow, power outflow, onsite usage, battery charge, and battery discharge**



Average Residential Usage - Hourly kW/Customer
Annual Load - 7,844 kWh
2.500000
2.000000
1.500000
1.000000
0.500000
0.000000
kW
1
188
375
562
749
936
1123
1310
1497
1684
1871
2058
2245
2432
2619
2806
2993
3180
3367
3554
3741
3928
4115
4302
4489
4676
4863
5050
5237
5424
5611
5798
5985
6172
6359
6546
6733
6920
7107
7294
7481
7668
7855
8042
8229
8416
8603
Hour

NREL PVWatts Calculator
Hourly Solar Output (AC) kW
System Capacity 6.28 kW (DC)
Fixed Tilt @ 20deg, Lansing MI

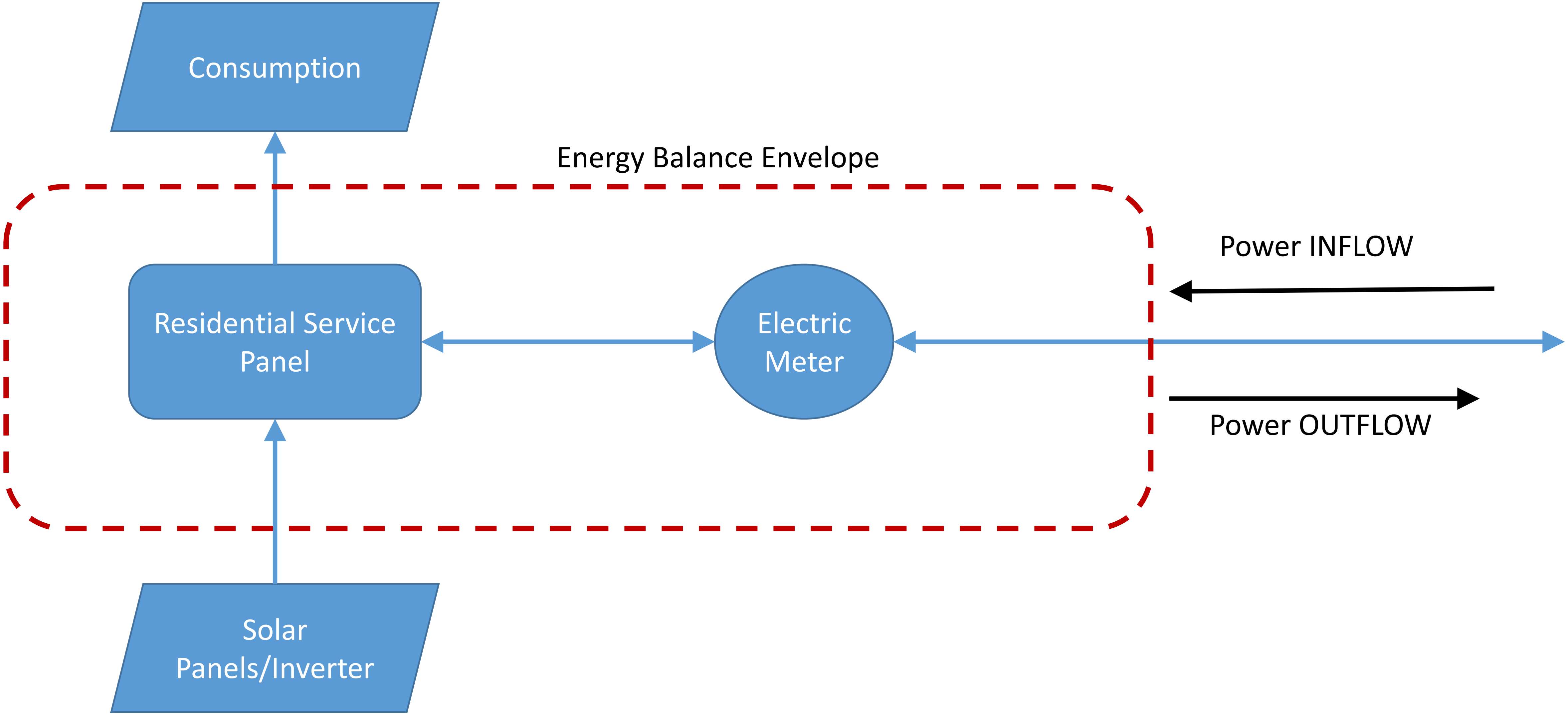


Modeling Mathematics

- The derivation of the mathematical relationships between generation and consumption, and power inflows and outflows, starts with an energy balance:

[Energy In = Energy Out] **Equation (1)**

Distributed Generation Customer Energy-Balance



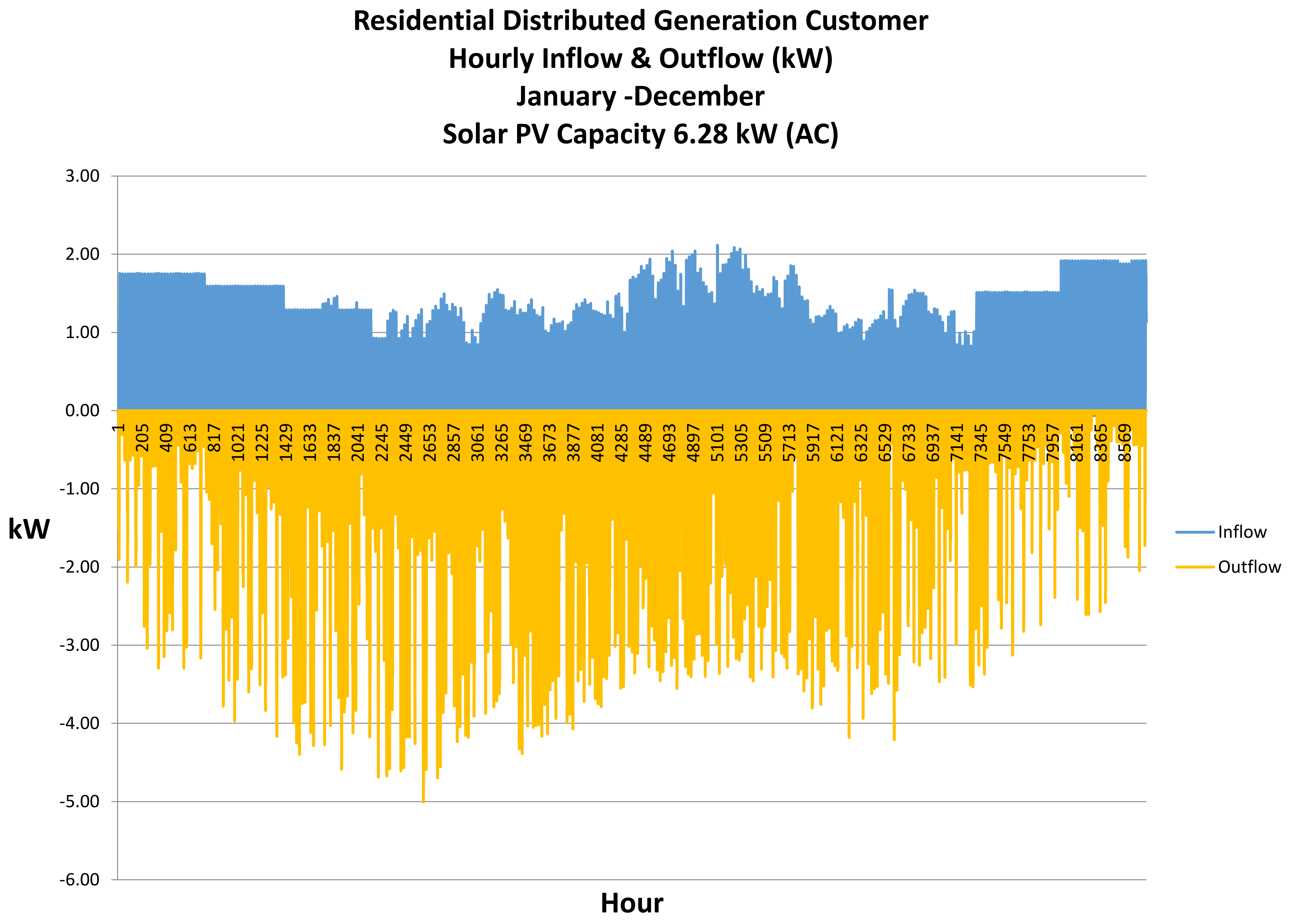
Energy Balance

- Inserting all energy flows intersecting the energy balance envelope [dashed line] into Equation (1), yields an exact relationship between the model's key input variables, generation and consumption, and the desired grid parameters, inflow and outflow; i.e.
- **[Generation + Inflow = Consumption + Outflow]   Equation (2)**
- Or alternately stated;
- **[Inflow – Outflow] = [Consumption – Generation]   Equation (3)**

Simplifying Assumption

- Consumption and generation data-output by the SAM and PVWatts® models are limited to hourly values.
- A **net positive (or negative)** value of [Consumption – Generation] over the course of an hour represents a practical estimate of the **integrated hourly inflow (or outflow)** for that hour.

In this manner, a stream of 8760 (hourly) inflows and outflows are developed from consumption and generation data.


Residential Distributed Generation Customer
Hourly Inflow & Outflow (kW)
January -December
Solar PV Capacity 6.28 kW (AC)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
kW
1
205
409
613
817
1021
1225
1429
1633
1837
2041
2245
2449
2653
2857
3061
3265
3469
3673
3877
4081
4285
4489
4693
4897
5101
5305
5509
5713
5917
6121
6325
6529
6733
6937
7141
7345
7549
7753
7957
8161
8365
8569
Hour
Inflow
Outflow

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Onsite Usage of Distributed Generation

Because onsite-usage can be quantified by reference to smart-metered power flows, it is the key to unlocking past barriers to implementation of cost-of-service based DG tariffs.

Calculation of Generation Used Onsite

Rearranging the energy balance (Eq. 3) yields two identities:

[Generation – Outflow] = [Consumption – Inflow] **Equation (4)**

These mathematical identities are recognized as representing the "onsite-usage" portion of the generation output.

Onsite usage = [Generation – Outflow] **Equation (5)**

And:

Onsite usage = [Consumption – Inflow] **Equation (6)**

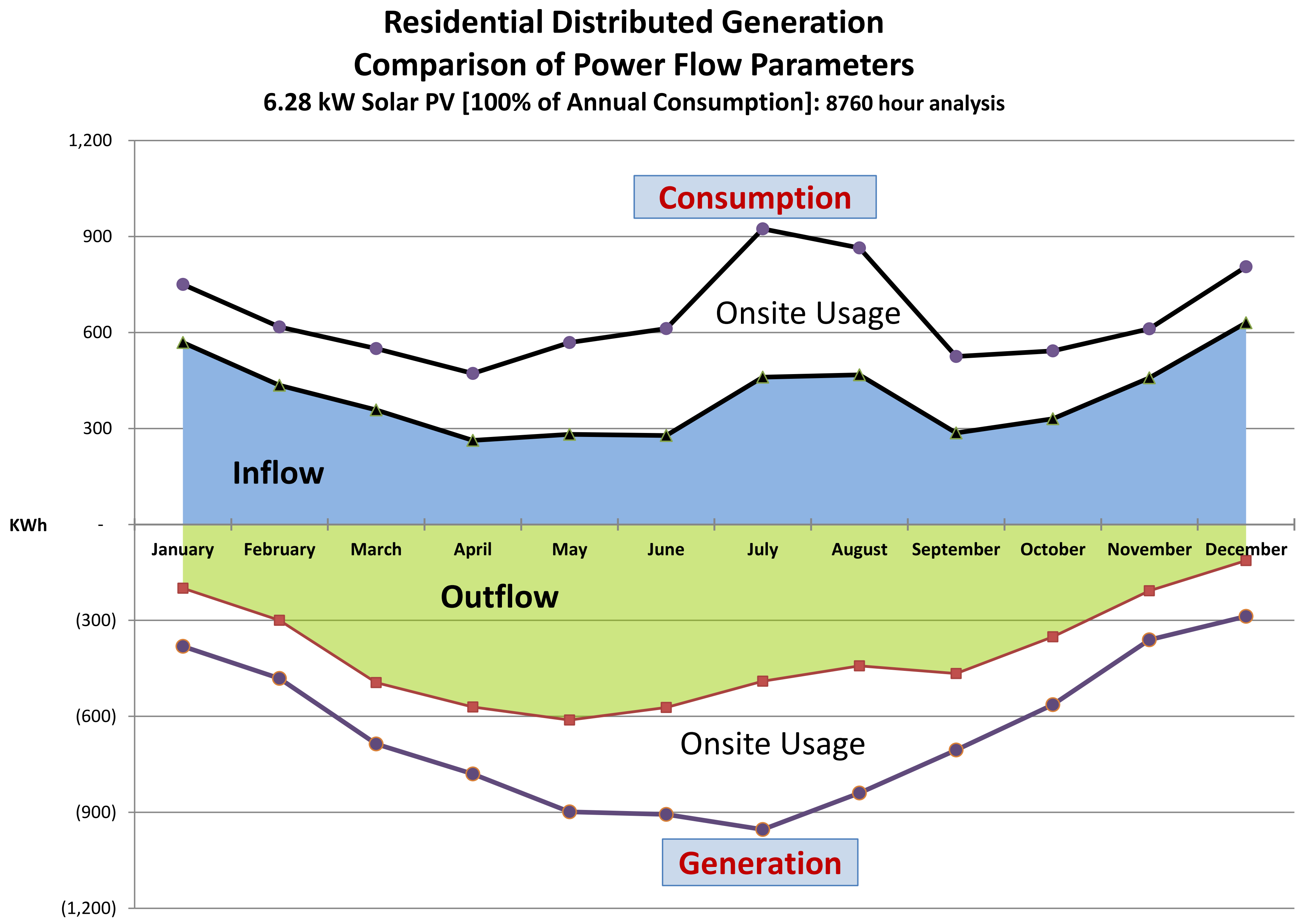
Inflow/Outflow as a Function of System Properties

The ***physical electrical system*** suggests that Equations (5) and (6) be rearranged to a form in which inflow and outflow are the dependent variables:

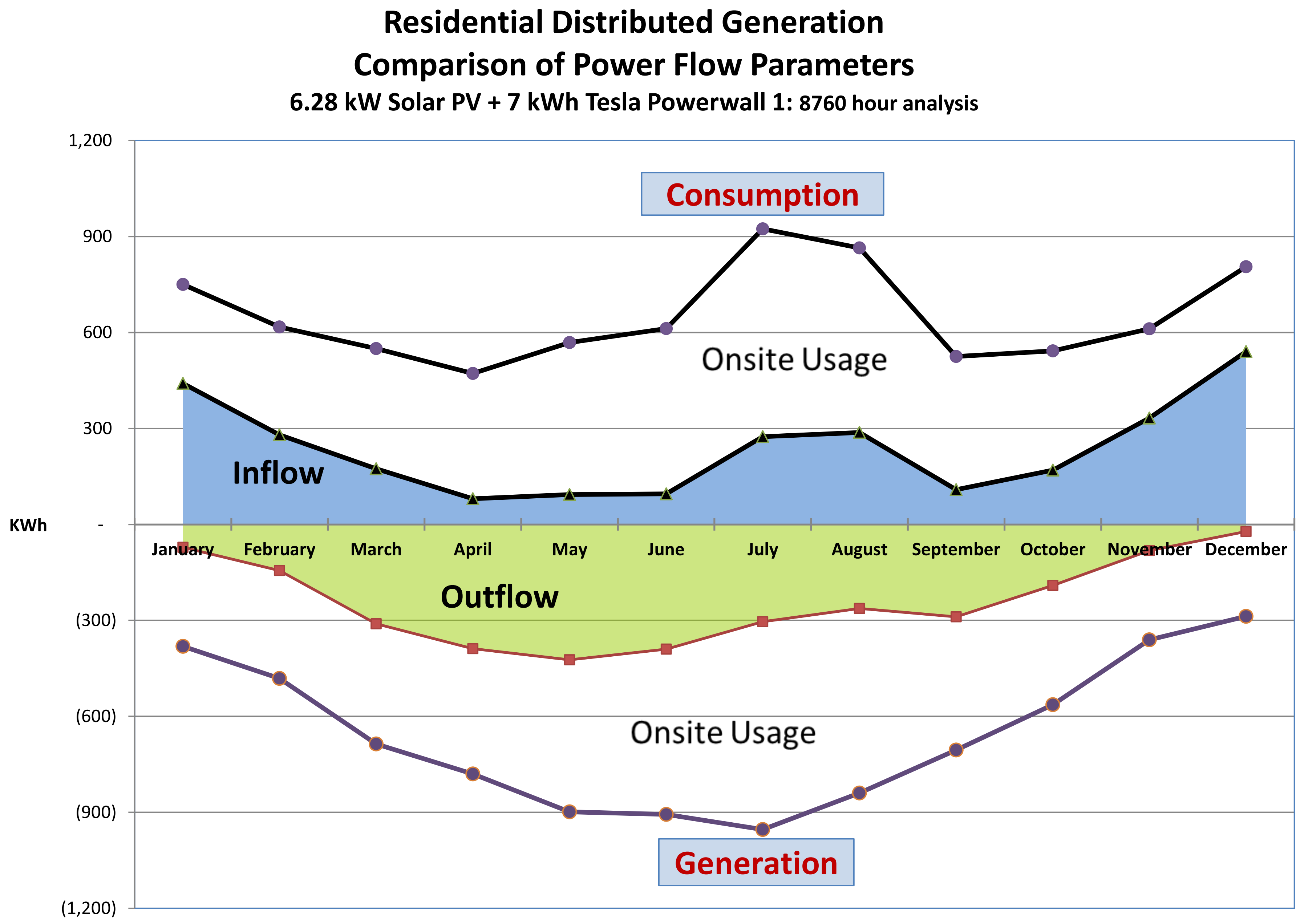
Inflow = [Consumption – Onsite Usage] **Equation (9)**

And:

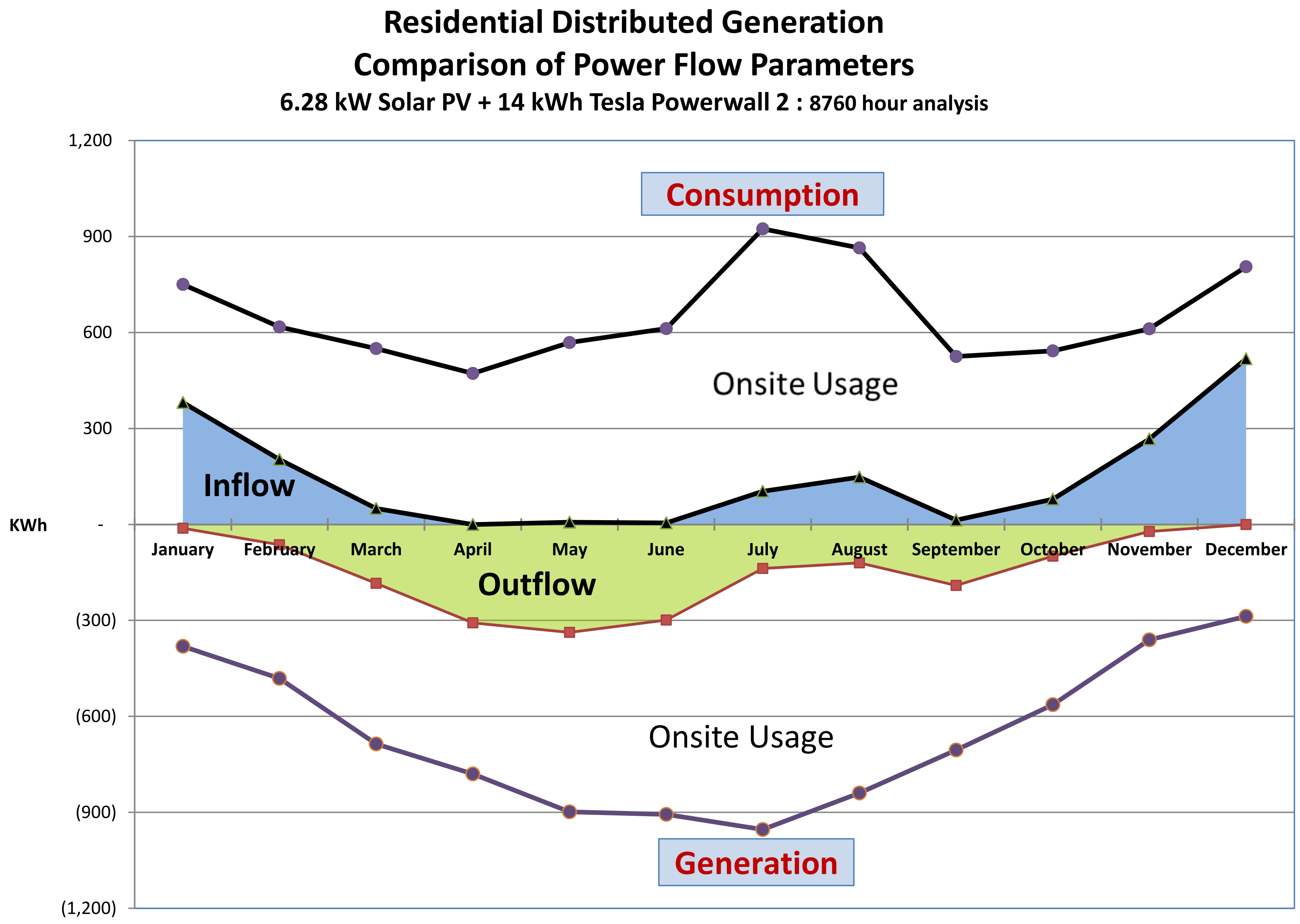
Outflow = [Generation – Onsite Usage] **Equation (10)**



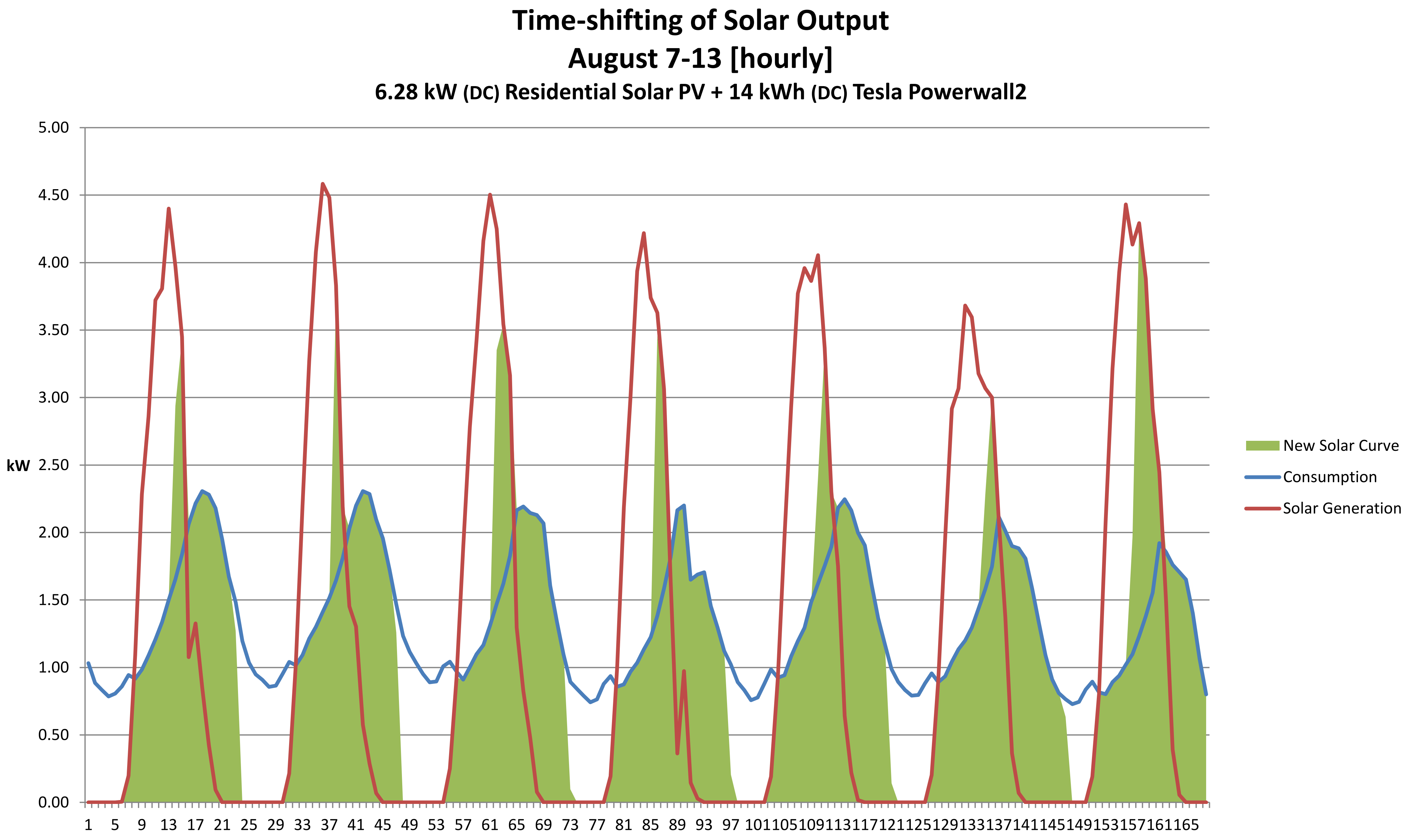
Residential Distributed Generation
Comparison of Power Flow Parameters
6.28 kW Solar PV [100% of Annual Consumption]: 8760 hour analysis
1,200
900
600
300
KWh
-
(300)
(600)
(900)
(1,200)
Consumption
Onsite Usage
Inflow
Outflow
Onsite Usage
Generation
January
February
March
April
May
June
July
August
September
October
November
December



Residential Distributed Generation
Comparison of Power Flow Parameters
6.28 kW Solar PV + 7 kWh Tesla Powerwall 1: 8760 hour analysis
1,200
900
600
300
-
(300)
(600)
(900)
(1,200)
KWh
Consumption
Onsite Usage
Inflow
Outflow
Onsite Usage
Generation
January
February
March
April
May
June
July
August
September
October
November
December

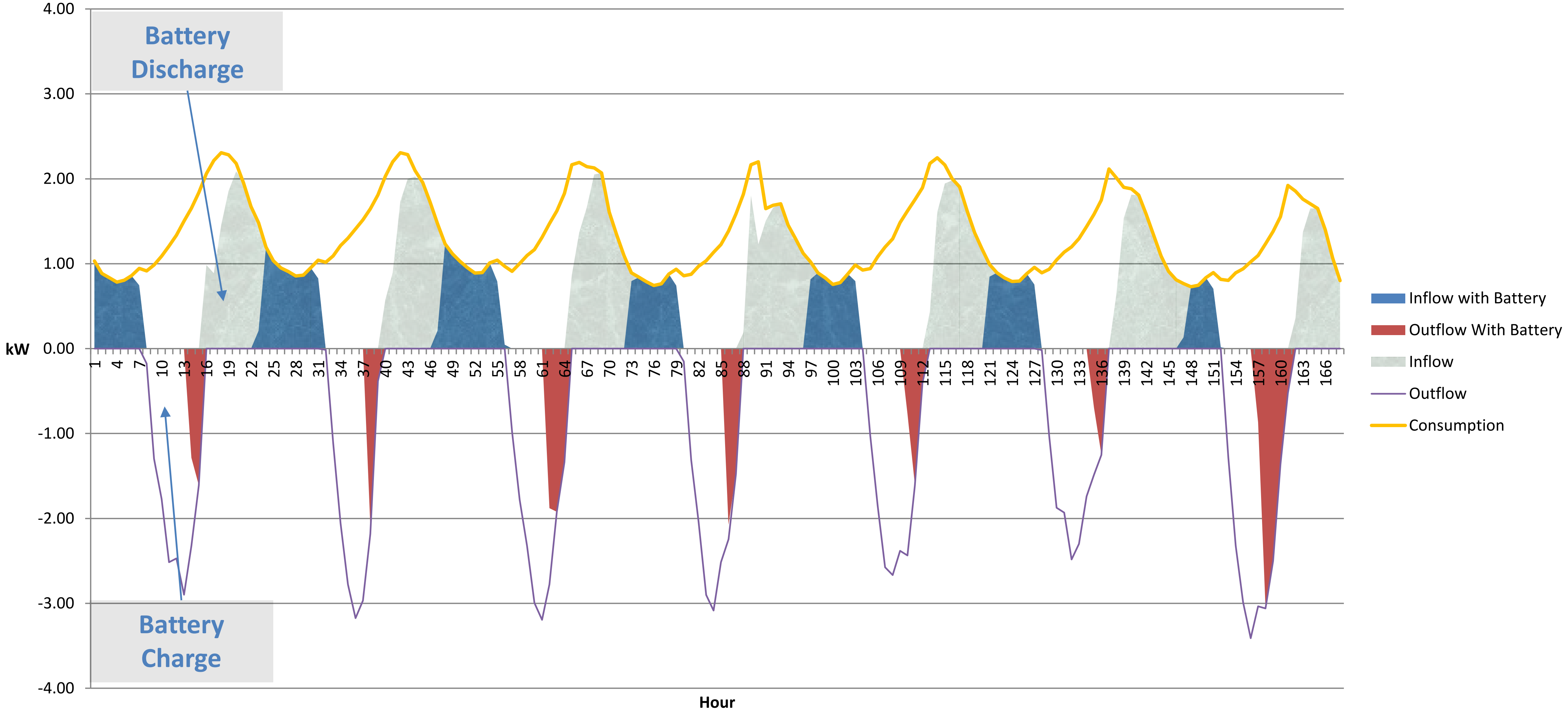


Residential Distributed Generation
Comparison of Power Flow Parameters
6.28 kW Solar PV + 14 kWh Tesla Powerwall 2 : 8760 hour analysis
1,200
900
600
300
-
(300)
(600)
(900)
(1,200)
KWh
Consumption
Onsite Usage
Inflow
Outflow
Onsite Usage
Generation
January
February
March
April
May
June
July
August
September
October
November
December



Time-shifting of Solar Output
August 7-13 [hourly]
6.28 kW (DC) Residential Solar PV + 14 kWh (DC) Tesla Powerwall2
kW
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101105109113117121125129133137141145149153157161165
New Solar Curve
Consumption
Solar Generation

Residential Hourly Peak-Demand Reduction
August 7-13 (Hourly)
6.28 kW (DC) Residential Solar PV + 14 kWh Tesla Powerwall 2



Observations

- Optimal operation of grid-interconnected DG systems occurs when onsite-usage is maximized [for a given level of PV Capacity]
  - If the level of generation physically used on-site could be increased, then to that extent, more efficient operation of the DG system is achieved
  - The timing of onsite usage is also a factor leading toward operational efficiency, e.g. peak demand reduction
  - I&O with battery storage mitigates the issue of two-way flows on radial distribution circuits with high penetration of customer sited solar PV

Conclusions

- If the economic payback to a customer under a particular regulatory mechanism is indifferent, or nearly indifferent, to changes in the level (and timing) of onsite-usage, then such mechanism is inherently flawed
  - Net Energy Metering (NEM) is indifferent to changes in the level/timing of generation used onsite
  - Buy-all Sell all (BASA) is indifferent to changes in the level/timing of generation used onsite

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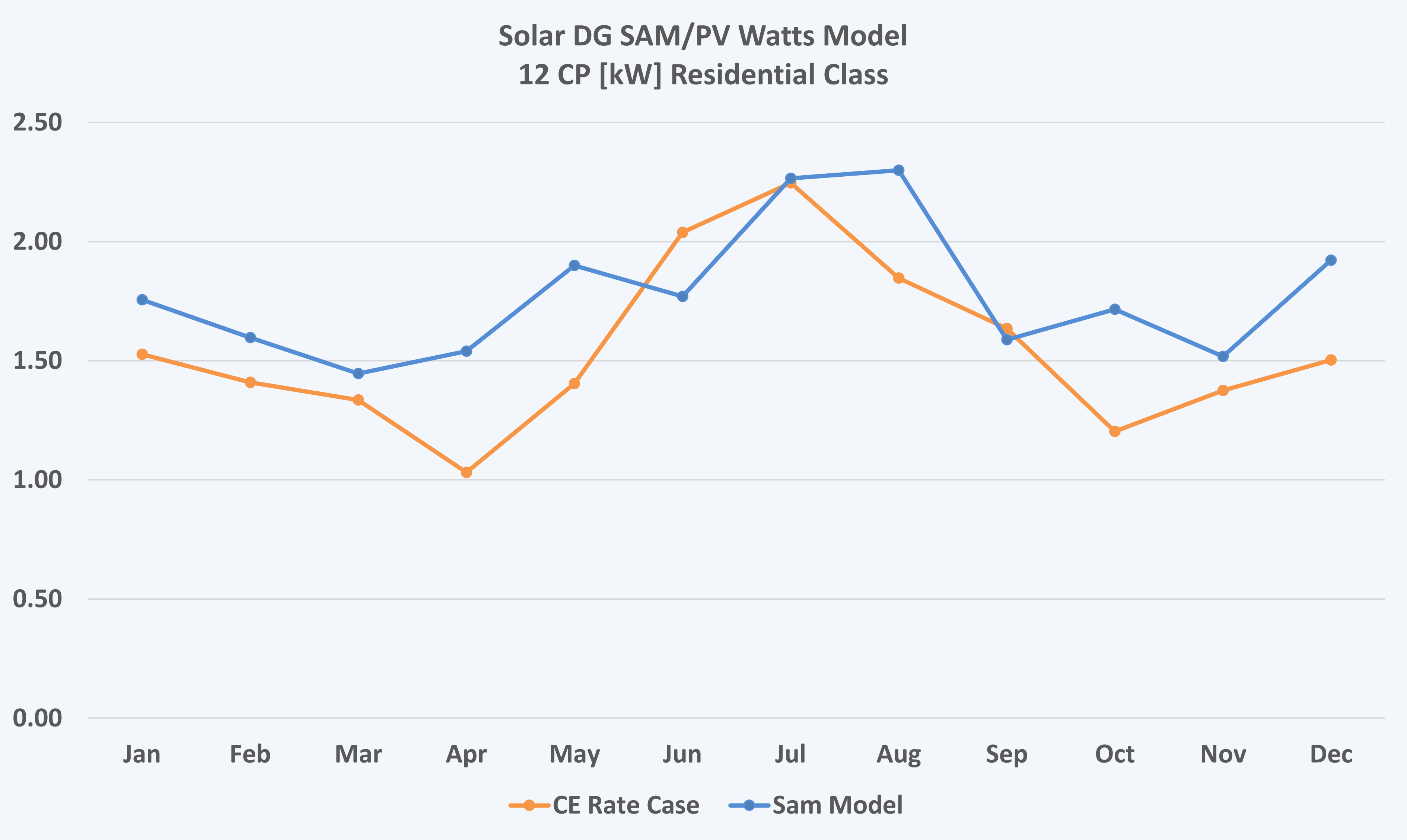
Findings related to Cost-of-Service

- Load diversity (i.e. power inflows) within the sub-group of residential DG customers can be significant
  - Residential DG peak-demand (inflow) is strongly correlated with the level of solar PV capacity vis-à-vis a customer’s annual load
  - Residential DG peak demand can be reduced by onsite energy storage operated to re-dispatch solar output (load following)

Good Correlation between Model and Rate Case Coincident Peaks

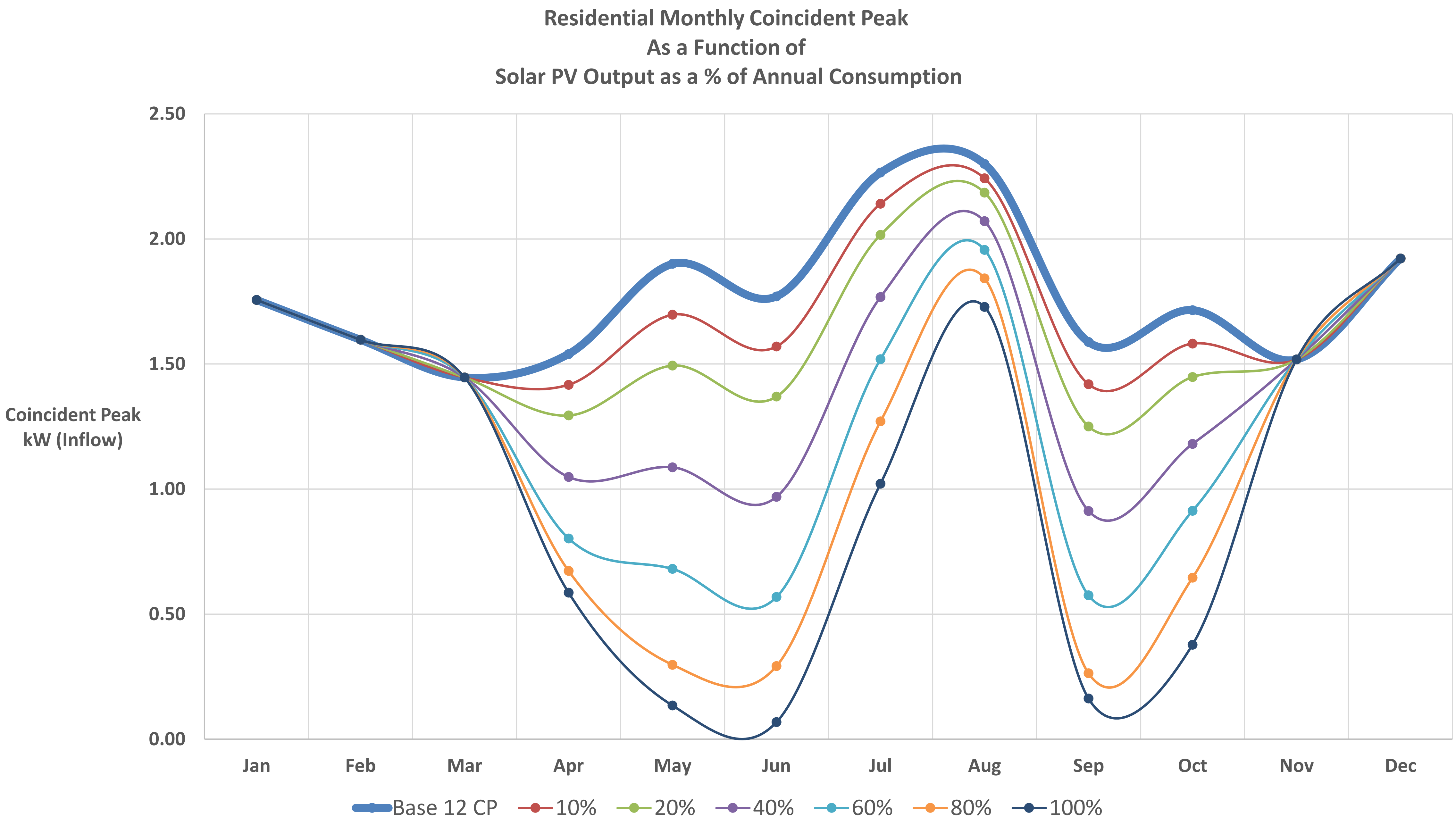
(Consumers Energy U-17990)



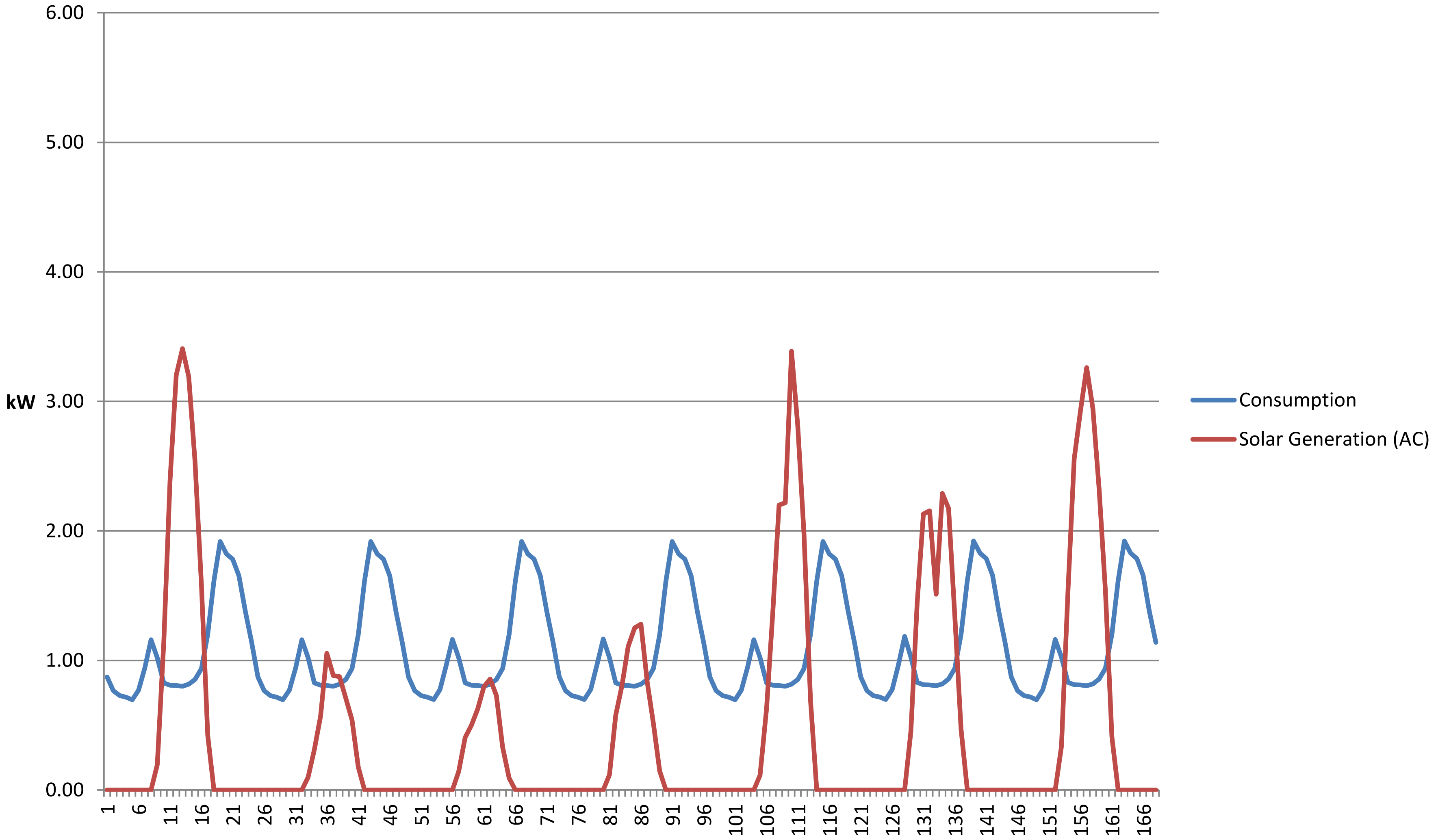
Comparison of 8760 Hour Model
To Approved Residential 4CP [CE U-17990]
Solar PV System Capacity [100% of Annual Consumption]

CE Rate Case U-17990		Model Solar DG	
4 CP	Residential RS +RT kW/Cust	Residential kW/Cust	Inflow kW/Cust
Jun	2.04	1.77	0.07
Jul	2.25	2.27	1.02
Aug	1.85	2.30	1.73
Sep	1.64	1.59	0.16
Total	7.8	7.9	3.0

With Solar PV


Residential Monthly Coincident Peak
As a Function of
Solar PV Output as a % of Annual Consumption
Coincident Peak
kW (Inflow)
2.50
2.00
1.50
1.00
0.50
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Base 12 CP
10%
20%
40%
60%
80%
100%

Residential Distributed Generation Customer Consumption and Generation December 11 - 17 [hourly] 6.28 kw (AC) Solar PV [100% of Annual Consumption]



Modeling Observations and Conclusion Regarding the COSS Segregation of Solar DG Customers

- Customers having small to moderate levels of PV capacity (relative to their annual consumption) have monthly **peak-demand profiles** that are similar to the full requirements customers
  - Like a smaller-than-average customer
- Customers having high levels of PV capacity have lower summer coincident peaks – but nearly identical winter coincident peaks as full requirements customers

Conclusion: COSS segregation of solar PV DG customers into a separate rate-class is not necessary

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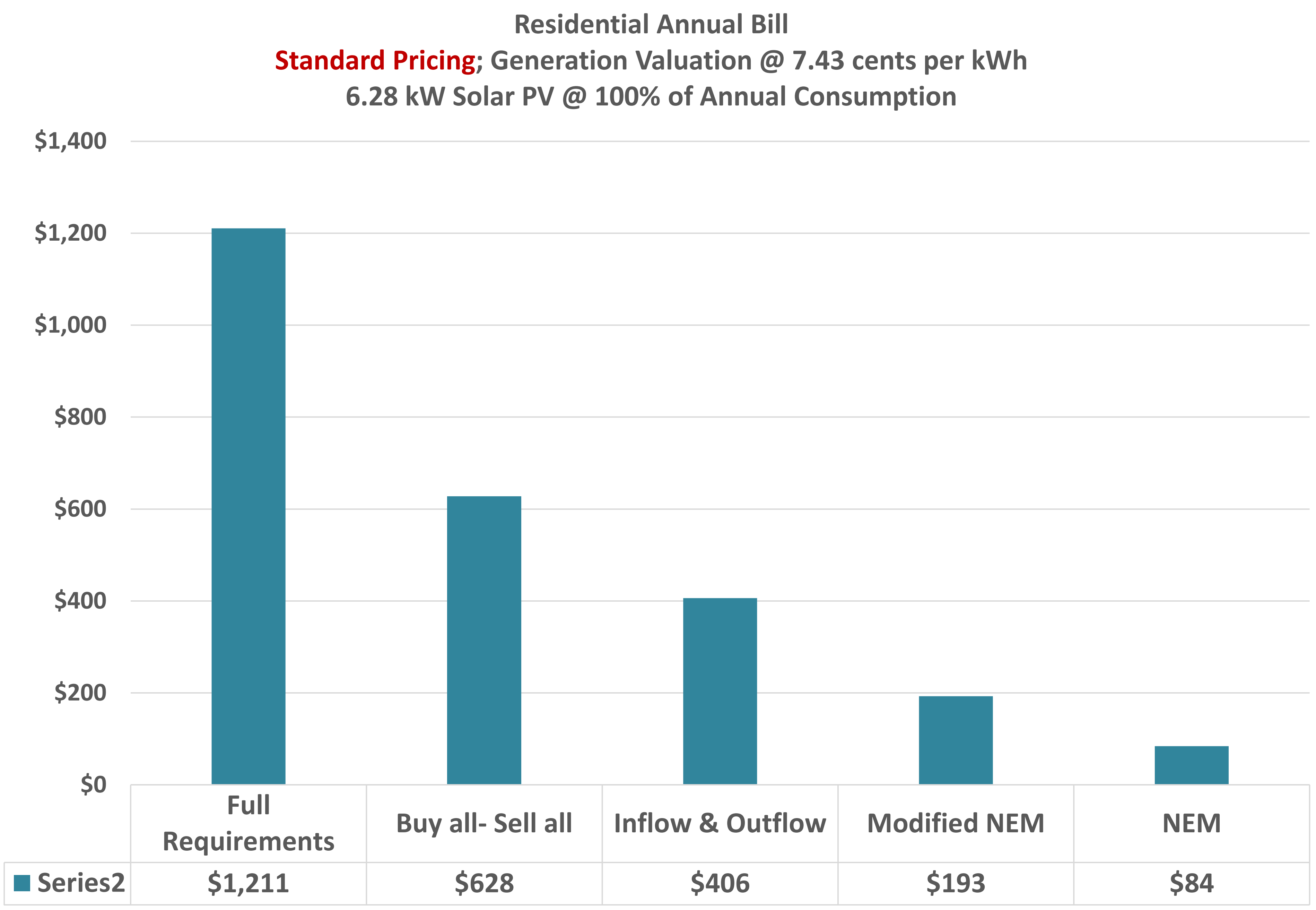
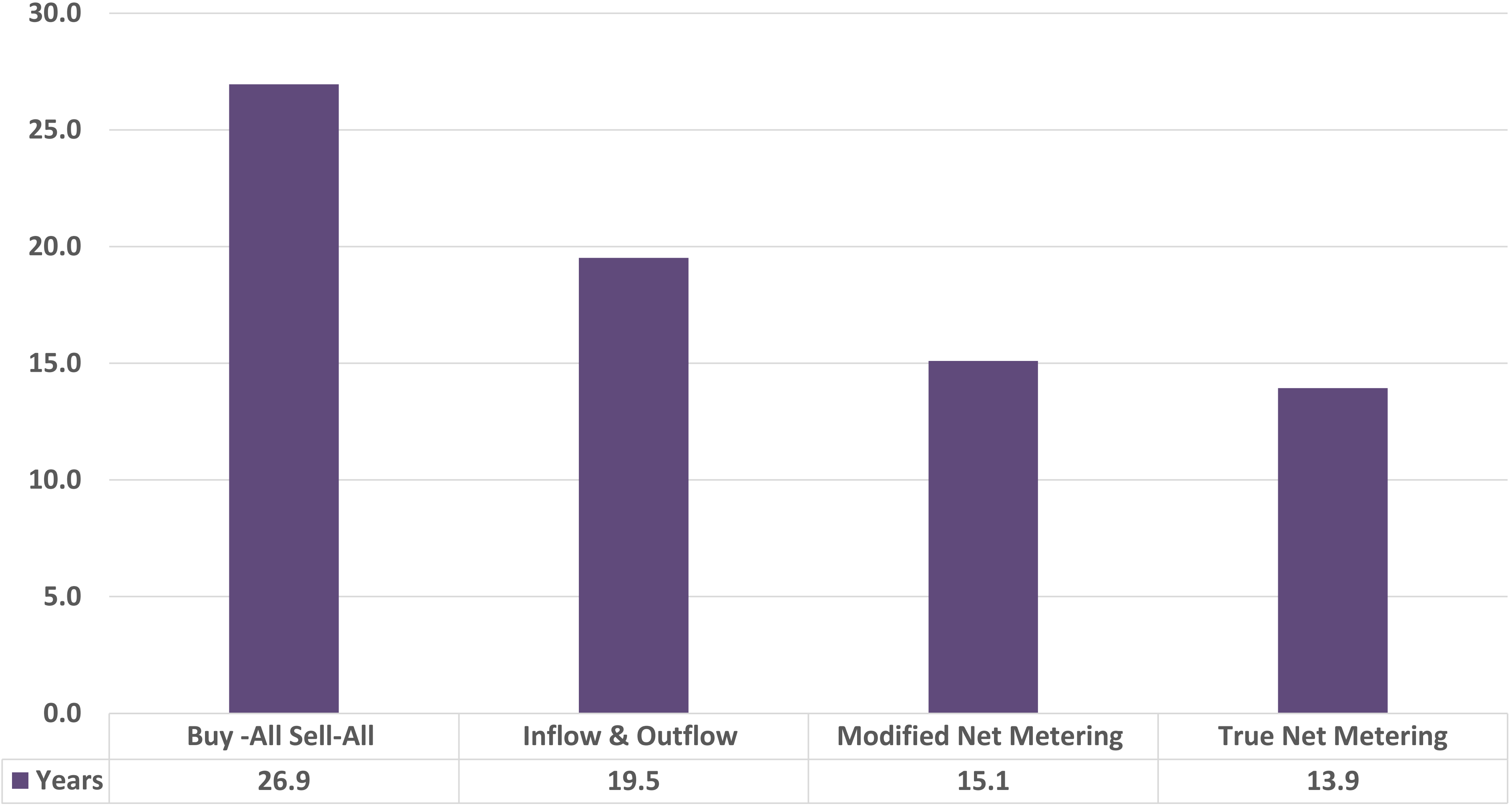

Residential Annual Bill
Standard Pricing; Generation Valuation @ 7.43 cents per kWh
6.28 kW Solar PV @ 100% of Annual Consumption
$1,400
$1,200
$1,000
$800
$600
$400
$200
$0
Full Requirements
Buy all- Sell all
Inflow & Outflow
Modified NEM
NEM
Series2
$1,211
$628
$406
$193
$84

Simple Payback

Installed Cost $15,700 $2.50/Watt (Excludes ITC)

6.28 kW Solar PV [100% of Annual Consumption]

Standard Residential Rate/7.43 cents/kWh Credit



Valuation of Solar PV Outflow

Effective Outflow Capacity Method

6.28 kW (AC) Solar PV [100% of Annual Purchases]	7,844 kWh
Credit -LMP Monthly Average MISO REAL TIME	0.035
Energy Loss Factor	0.079
Value of Energy $/kWh	0.038002172
Cost of New Entry (CONE) $/kW-yr	$ 94.80
100% of CONE $/kW-Yr	$ 94.80
Nameplate Capacity kW (DC)	6.28
Outflow Capacity factor [Outflow/Generation]	61.4%
Effective Load Carrying Capacity (ELCC)	44%
Effective Capacity kW (AC)	1.70
Capacity Credit - $/Yr	$160.93
Capacity Loss Factor	0.079
Capacity Credit [$/Yr]	**$ 174.74**
Annual Outflow kWh	4818
Capacity Value $/kWh	$ 0.036
Value of Generation $/kWh	**$ 0.0743**

1.26 kW Solar PV [20% of Annual Purchases]	1,569 kWh
Credit -LMP Monthly Average MISO REAL TIME	0.035
Energy Loss Factor	0.079
Value of Energy $/kWh	0.038002172
Cost of New Entry (CONE) $/kW-yr	$ 94.80
100% of CONE $/kW-Yr	$ 94.80
Nameplate Capacity kW (DC)	1.26
Outflow Capacity Factor [Outflow/Generation]	6.5%
Effective Load Carring Capacity (ELCC)	44%
Effective Capacity kW (AC)	0.04
Capacity Credit - $/Yr	$3.39
Capacity Loss Factor	0.079
Capacity Credit [$/Yr]	**$ 3.68**
Annual Outflow kWh	101
Capacity Value $/kWh	$ 0.036
Value of Generation $/kWh	**$ 0.0743**

Conclusions and Recommendations

1. The Inflow & Outflow Mechanism should be adopted as the replacement mechanism for NEM as it provides the best option for achieving:
    1. Clear and accurate pricing signals encouraging optimal operation of DG systems and rational economic behavior of customers
    2. Retail rates based on Cost-of-Service (COS)
2. Modeling *suggests* that initial deployment of the I&O mechanism should have **combined COSS allocations** with the underlying full requirements tariffs [i.e. no separate DG rate classes].
3. **Dynamic pricing** provides enhanced transparency of price signals and thus could be required as a condition for customer enrollment in any future I&O tariff.
4. The feasibility of *load control* and *energy waste reduction* program **incentives** should be investigated as a tool to further develop this energy resource.
5. Outflow credits should be based on the *effective outflow-capacity method* or the Commission's approved PURPA rate; [standard rate for all program participants].
6. Tariffs should be **simple** and readily understandable.

Thank You!

Robert G. Ozar

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