

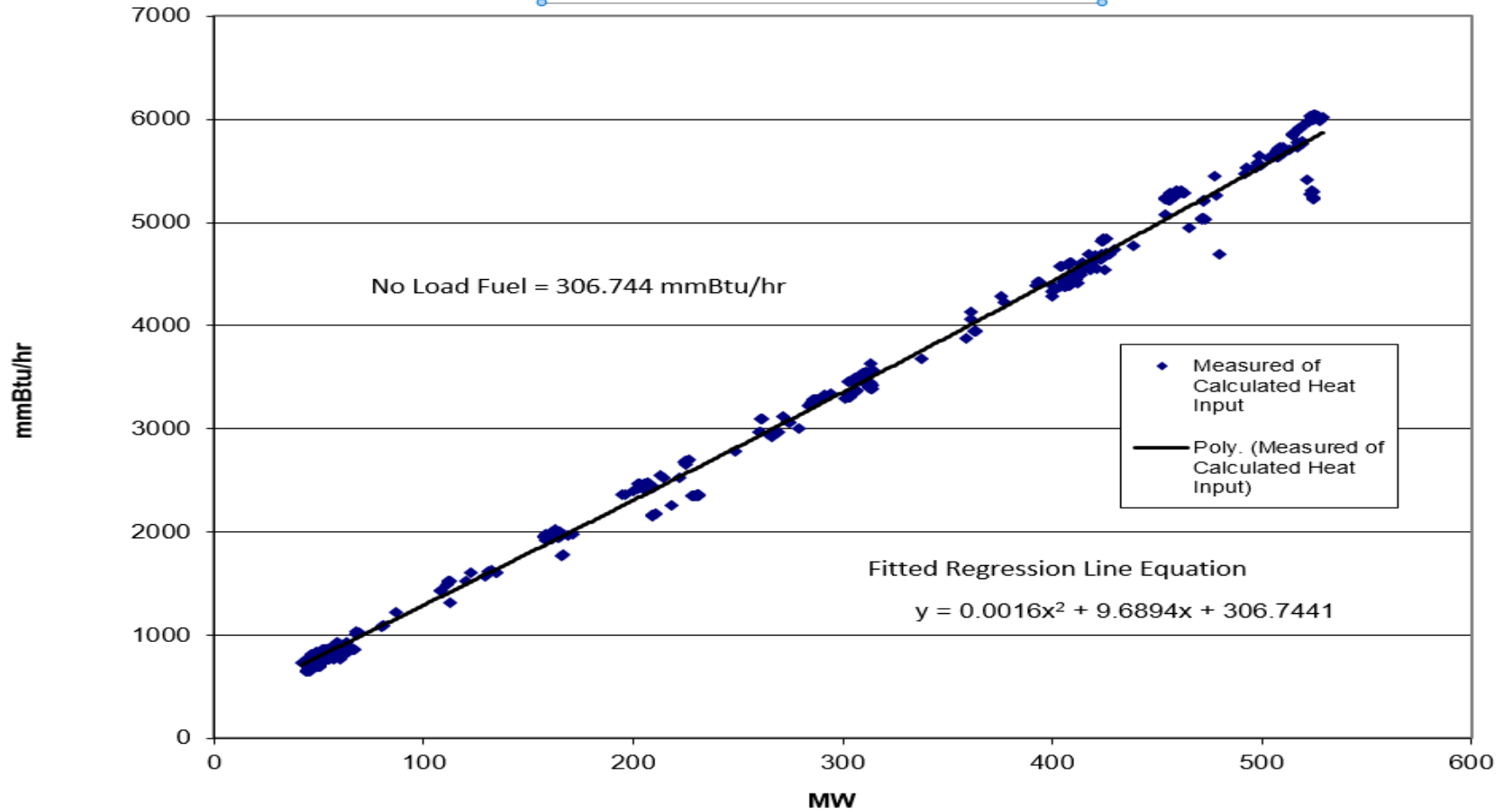
No-Load and Incremental Energy Offer Numerical Examples

Tom Hauske
Performance Compliance
Cost Development Subcommittee
February 16, 2021

- Data needed to create a No-Load and Incremental Energy Offer
 - Fuel Price (methodology in Fuel Cost policy)
 - Heat Input or Heat Rate Curve
 - Performance Factor
 - Maintenance Adder
 - Operating Cost Adder
 - Emissions Adders
- The bottom 5 items above are values Market Sellers input into MIRA

- Heat Input Curves are created from:
 - Normal operations data using plant instrumentation
 - Only steady state operation data should be used
 - Performance Test
 - OEM supplied design heat balances
- EXCEL or other data analysis tools used to determine A, B, C, coefficients for polynomial heat input equation
 - Heat Input = $A + B*x + C*x^2 + \dots$
 - Where x = MWh

**Typical Oil Heat Input Output Curve
for 550 MW Steam Unit
from Plant Instrumentation Data**



- Heat Input Curve Coefficients
 - $A = 306.7441$
 - $B = 9.6894$
 - $C = 0.0016$

- Heat Input Curve
 - Heat Input = $306.7441 + 9.6894*(MWh) + 0.0016*(MWh)^2$

- Heat Input Curves are submitted to PJM and the IMM by MIRA's Cost Offer Assumption's Module (COA)
 - $X^0 = A$, $X^1 = B$, $X^2 = C$, and $X^3 = D$

Schedule ID	1
Schedule Name	2X1 Gas
Schedule Description	2 CTs and 1 ST gas fired

Performance Factor	<input type="text" value="1.0000000000"/>	+ Add Output Range
--------------------	---	------------------------------------

Output Range (MW)		Heat Input Polynomial Coefficients	Fuel Shares		Actions
From	To		Energy Source	Share	
0.0	<input type="text" value="100.0"/>	X^0 <input type="text"/> X^1 <input type="text"/> X^2 <input type="text"/> X^3 <input type="text"/>	Fuel 1 <input type="text" value="NG"/> Fuel 2 <input type="text" value="[Select One]"/> Fuel 3 <input type="text" value="[Select One]"/>	<input type="text"/> <input type="text"/> <input type="text"/>	<input type="button" value="🗑"/>
100.1	<input type="text" value="200.0"/>	X^0 <input type="text"/> X^1 <input type="text"/> X^2 <input type="text"/> X^3 <input type="text"/>	Fuel 1 <input type="text" value="NG"/> Fuel 2 <input type="text" value="[Select One]"/> Fuel 3 <input type="text" value="[Select One]"/>	<input type="text"/> <input type="text"/> <input type="text"/>	<input type="button" value="🗑"/>

- Input Variable for the Example
 - Total Fuel related Cost = \$14.00/MMBtu
 - Performance Factor (PF) = 1.02
 - Maintenance and Operating Cost adders (VOM) = \$0.15/MMBtu
 - Emissions adders = \$0

- No-Load Fuel is the total fuel to sustain zero net output MW at synchronous generator speed.

$$\text{using heat input} = 306.7441 + 9.6894 * (\text{MWh}) + 0.0016 * (\text{MWh})^2$$

$$\text{at 0 MWh} = 306.7441 + 9.6894 * (0) + 0.0016 * (0)^2 \text{ (MMBtu/hour)}$$

$$\text{No-Load Heat} = 306.7441 \text{ MMBtu/hour}$$

- No-Load Cost is the hourly cost required to create the starting point of a monotonically increasing incremental offer curve for a generating unit.

$$\text{No-Load Cost} = \text{No-Load Fuel} * \text{PF} * (\text{TFRC} + \text{VOM}) \text{ (\$/hour)}$$

$$= 306.7441 * 1.02 * (14.0 + 0.15) \text{ (\$/hour)}$$

$$\text{No-Load Cost} = \$4,427.24 \text{ per hour}$$

- Two ways to calculate incremental energy offers
 - Block Offers
 - Block difference in Total Operating Cost
 - Slope Offers
 - Incremental Heat Rate Curve

- Calculate Total Operating Costs using total fuel related cost equation from M15 Section 2.3.3

$$TotalFuelRelatedCosts =$$

$$FuelCosts + FuelRelatedCosts + SO_2 AllowanceCost + CO_2 AllowanceCost + NO_x AllowanceCost + MaintenanceAdder$$

- Simplifies to:

$$\begin{aligned}
 \text{Total Operating Cost (\$/hr)} &= \text{Heat Input} * \text{PF} * (\text{Fuel Cost} + \text{VOM}) \\
 &= \text{Heat Input} * 1.02 * (14.00 + 0.15)
 \end{aligned}$$

$$\begin{aligned}
 \text{Total Operating Cost (50 MWh)} &= \text{Heat Input(50 MWh)} * \text{PF} * (\text{Fuel Cost} + \text{VOM}) (\$/\text{hour}) \\
 &= 795.12 * 1.02 * (14.00 + 0.15) \\
 &= 11,476 \text{ \$/hour}
 \end{aligned}$$

Output (MWh)	Heat Input (mmBtu/hr)	Operating Cost (\$/hr)
50	795.12	11,476
160	1897.08	27,381
310	3460.75	49,949
410	4542.29	65,559
525	5824.73	84,068
550	6109.00	88,171

Incremental Cost (160 MWh) =

$[\text{Total Operating Cost (160 MWh)} - \text{Total Operating Cost (50 MWh)}] / [160 \text{ MWh} - 50 \text{ MWh}] (\$/\text{MWh})$

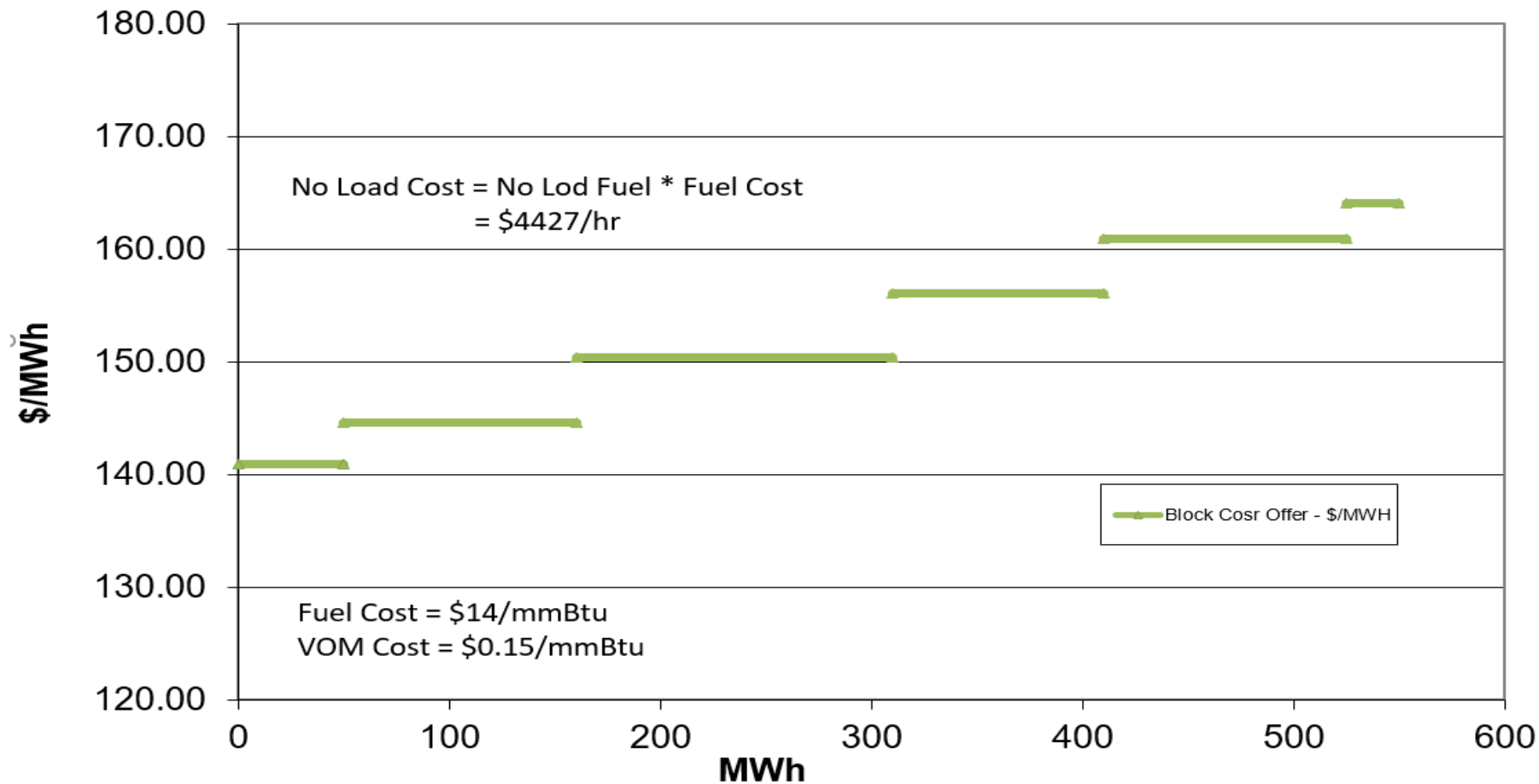
$= [27,381 - 11,476] / [160 - 50]$

$= \$144.59 \text{ per MWh}$

Output (MWh)	Incremental Offer (\$/MWh)
50	140.98*
160	144.59
310	150.46
410	156.10
525	160.95
550	164.11

* When calculating the first incremental the No-Load Cost is used for Total Operating Cost at MWh (0)

Typical Oil
Heat Rate & Cost Curves
for 550 MW Steam Unit



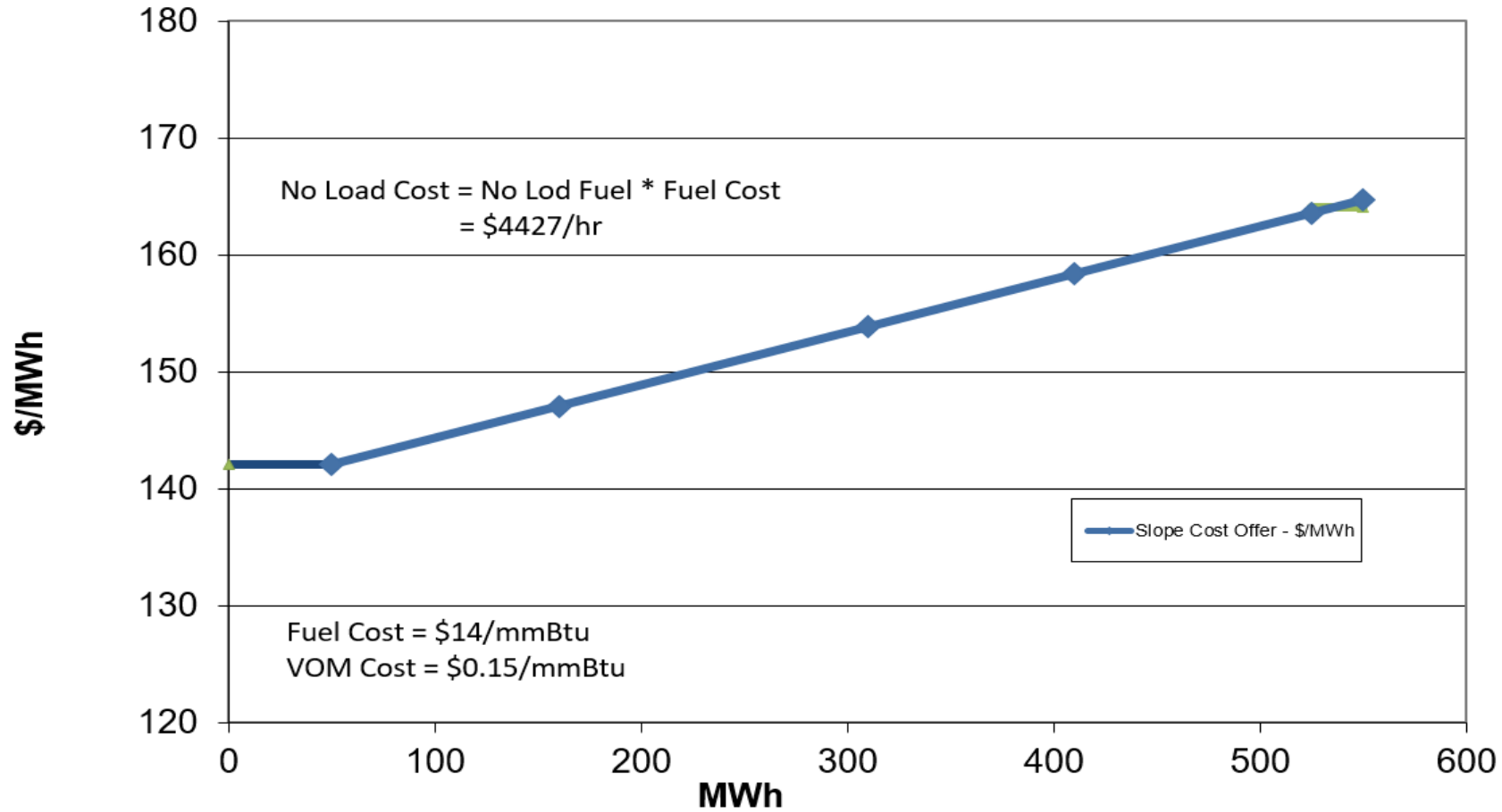
- Slope Offers are calculated using the incremental heat rate equation which is the derivative of the Heat Input equation
 - Heat Input = $306.7441 + 9.6894 * (\text{MWh}) + 0.0016 * (\text{MWh})^2$
 - Incremental Heat Rate (IHR) = $9.6894 + (2 * 0.0016 * (\text{MWh}))$

- Including Fuel and VOM Cost
 - Incremental Offer (\$/MWh) = $\text{IHR} * \text{PF} * (\text{Fuel Cost} + \text{VOM})$

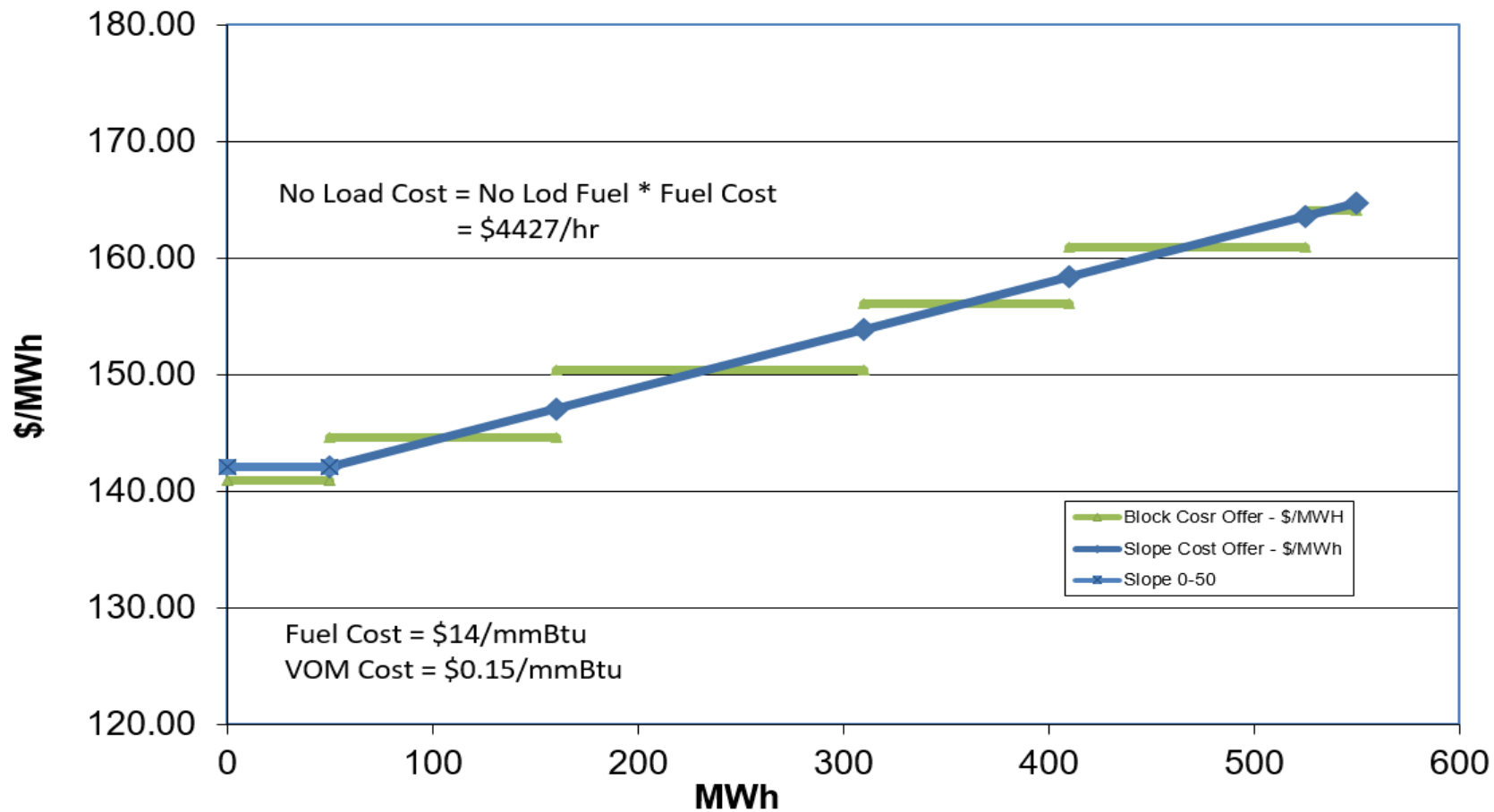
$$\begin{aligned}
 \text{Incremental Cost (50 MWh)} &= \text{IHR} * \text{PF} * (\text{Fuel Cost} + \text{VOM}) \\
 &= [9.6894 + (2 * 0.0016 * 50)] * 1.02 * (14.00 + 0.15) \\
 &= \$142.10 \text{ per MWh}
 \end{aligned}$$

Output (MWh)	Incremental Offer (\$/MWh)
50	142.10
160	147.07
310	153.84
410	158.36
525	163.55
550	164.68

Typical Oil
Heat Rate & Cost Curves
for 550 MW Steam Unit

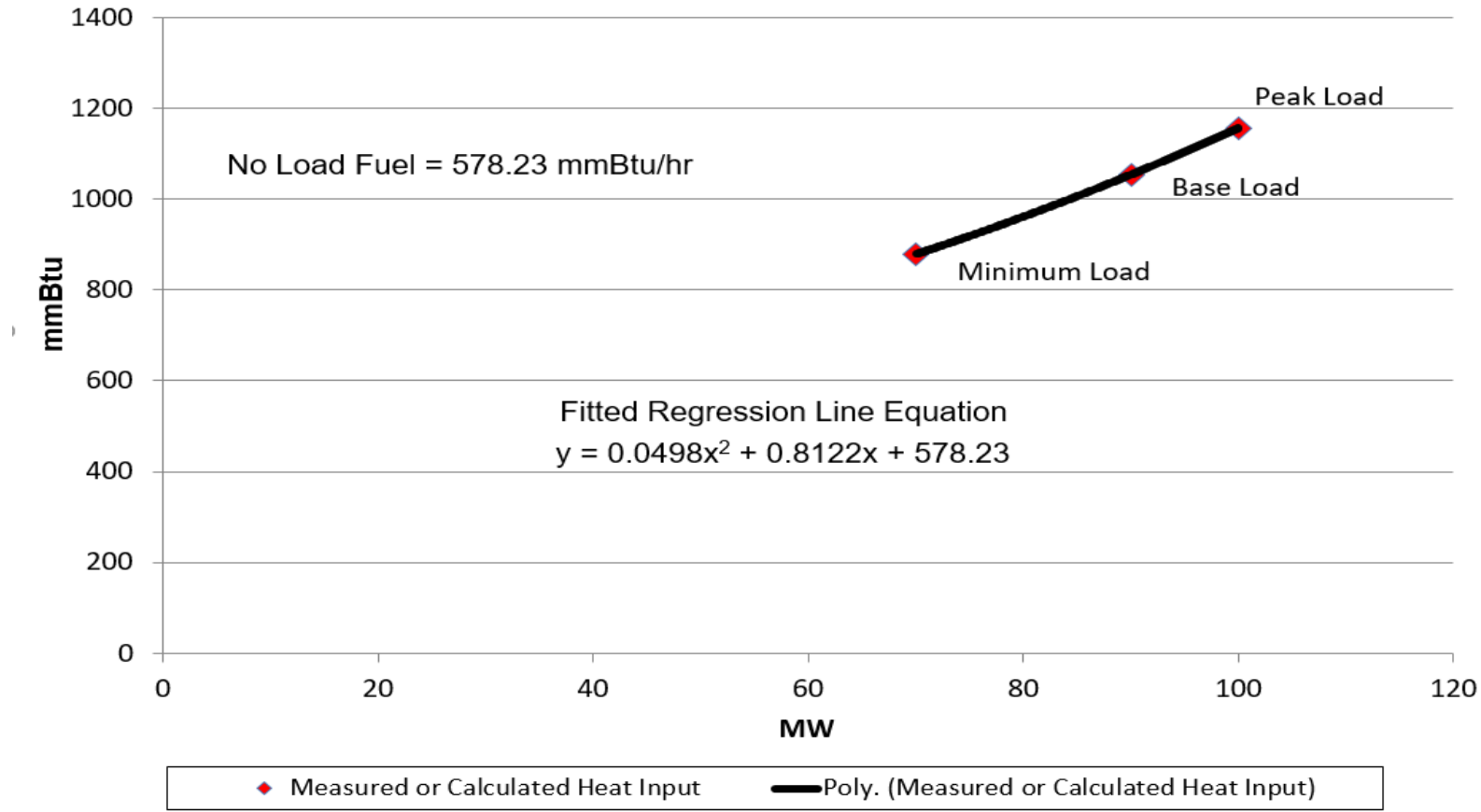


Typical Oil
Heat Rate & Cost Curves
for 550 MW Steam Unit



- 100 MW simple cycle combustion turbine
 - With fuel cost = \$/MMBtu
 - performance factor = 1.02
 - 70 MW minimum load
 - Maintenance Adder of \$75 / equivalent service hour (ESH)
 - 10 MW peak firing step with a maintenance factor of 4 for peak firing step

Combustion Turbine with Peak Firing Step Heat Input Curve



- Heat Input Curve
 - Heat Input = $578.23 + 0.8122*(MWh) + 0.0498*(MWh)^2$
- Heat Input Curve Coefficients
 - $A = 578.23$
 - $B = 0.8122$
 - $C = 0.0498$
- No-Load Heat = 578.23 MMBtu/hr

- Calculate No-Load Cost

$$\begin{aligned} \text{No-Load Cost} &= [\text{No-Load Fuel} * \text{PF} * \text{TFRC}] + \text{VOM}^{**} (\$/\text{hour}) \\ &= [578.23 * 1.02 * 4.0] + 0 (\$/\text{hr}) \end{aligned}$$

$$\text{No-Load Cost} = \$2359.18 \text{ per hour}$$

- Calculate Total Operating Cost

- Total Operating Cost (\$/hour) = [Heat Input * PF * Fuel Cost] + [Maintenance Factor[#] * VOM^{**}]

$$= [\text{Heat Input} * 1.02 * 4.00] + [\text{MF} * \text{VOM}]$$

** VOM in \$/ESH can be added to either No-Load or first incremental but not both

Maintenance Factor is equal to 1 for base load and below and equal to (4-1) for peak firing step

$$\begin{aligned}
 \text{Total Operating Cost (70 MWh)} &= (\text{Heat Input(70 MW)} * \text{PF} * \text{Fuel Cost}) + \text{VOM (\$/hr)} \\
 &= (879.02 * 1.02 * 4.00) + 75 \\
 &= 3,662 \text{ \$/hour}
 \end{aligned}$$

Output (MWh)	Heat Input (mmBtu/hr)	Operating Cost (\\$/hr)
70	879.02	3,662
90	1054.57	4,378
100	1157.28	5,022

Incremental Cost (90 MWh) =
 [Total Operating Cost (90 MWh) – Total Operating Cost (70 MWh)] / [90 MWh - 70 MWh] (\$/MWh)
 = [4,378 – 3,662] / [90 – 70]
 = \$35.82 per MWh

Output (MWh)	Incremental Offer (\$/MWh)
70	18.61*
90	35.82
100	64.42

* When calculating the first incremental the No-Load Cost is used for Total Operating Cost at MWh (0)

- Slope Offers are calculated using the incremental heat rate equation which is the derivative of the Heat Input equation
 - Heat Input = $578.23 + 0.8122*(MWh) + 0.0498*(MWh)^2$
 - Incremental Heat Rate (IHR) = $0.8122 + (2 * 0.0498*MWh)$

- Including Fuel and VOM Cost
 - Incremental Offer (\$/MWh) = $[IHR * PF * Fuel Cost] + [(Maintenance Factor^{\#} * VOM) / (MWh(1) - MWh(0))]$

Maintenance Factor is equal to 1 for base load and below and equal to (4-1) for peak firing step

Incremental Cost (100 MWh) =

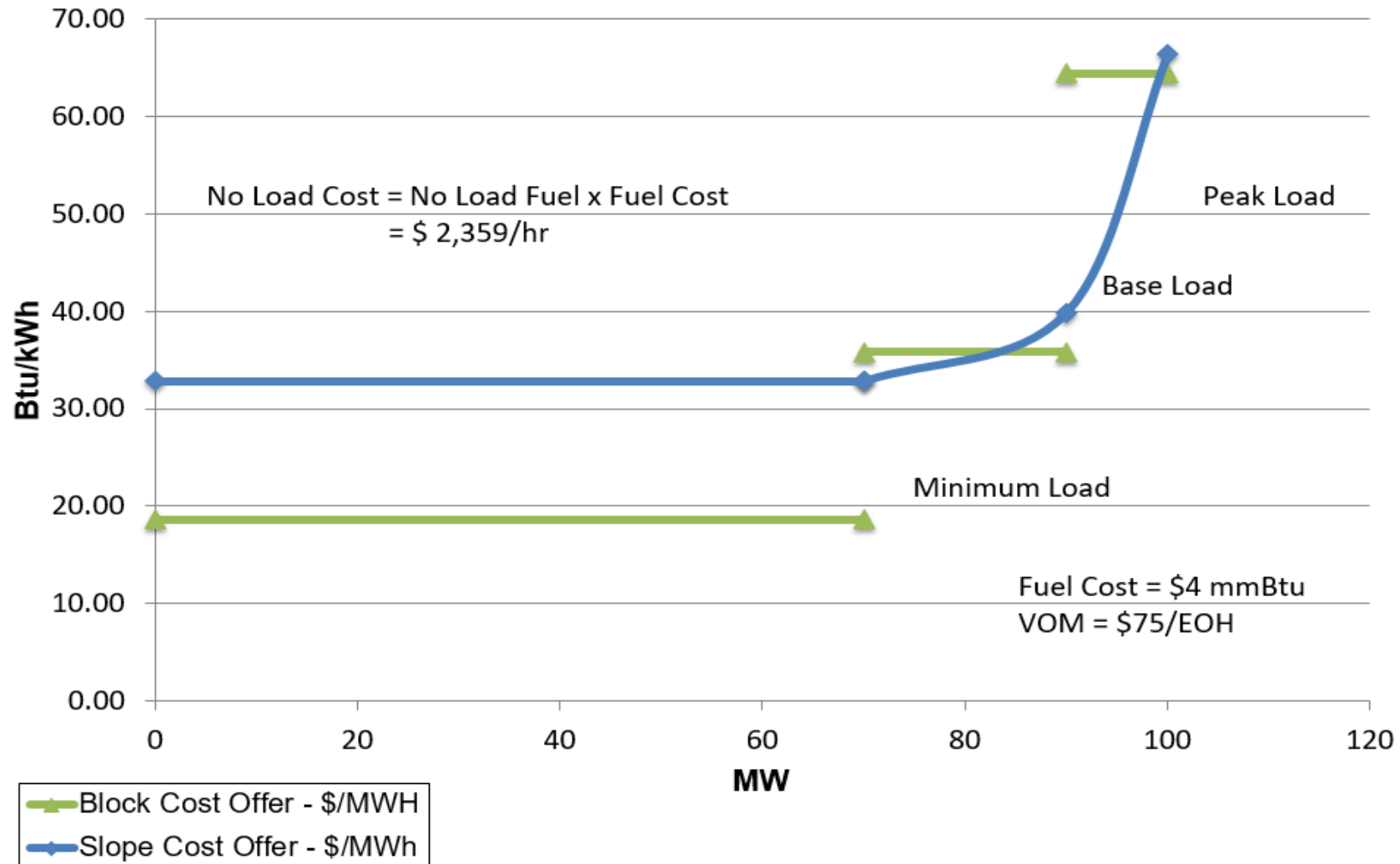
$$[\text{Incremental Offer (\$/MWh)} = [\text{IHR} * \text{PF} * \text{Fuel Cost}] + [(\text{Maintenance Factor}^\# * \text{VOM}) / (\text{MWh}(1) - \text{MWh}(0))] \text{ \$/MWh}$$

$$= [(0.8122 + (2 * 0.0498 * 100)) * 1.02 * 4] + [((4 - 1) * 75) / (100 - 90)]$$

$$= \$66.45 \text{ per MWh}$$

Output (MWh)	Incremental Offer (\\$/MWh)
70	32.83
90	39.89
100	66.45

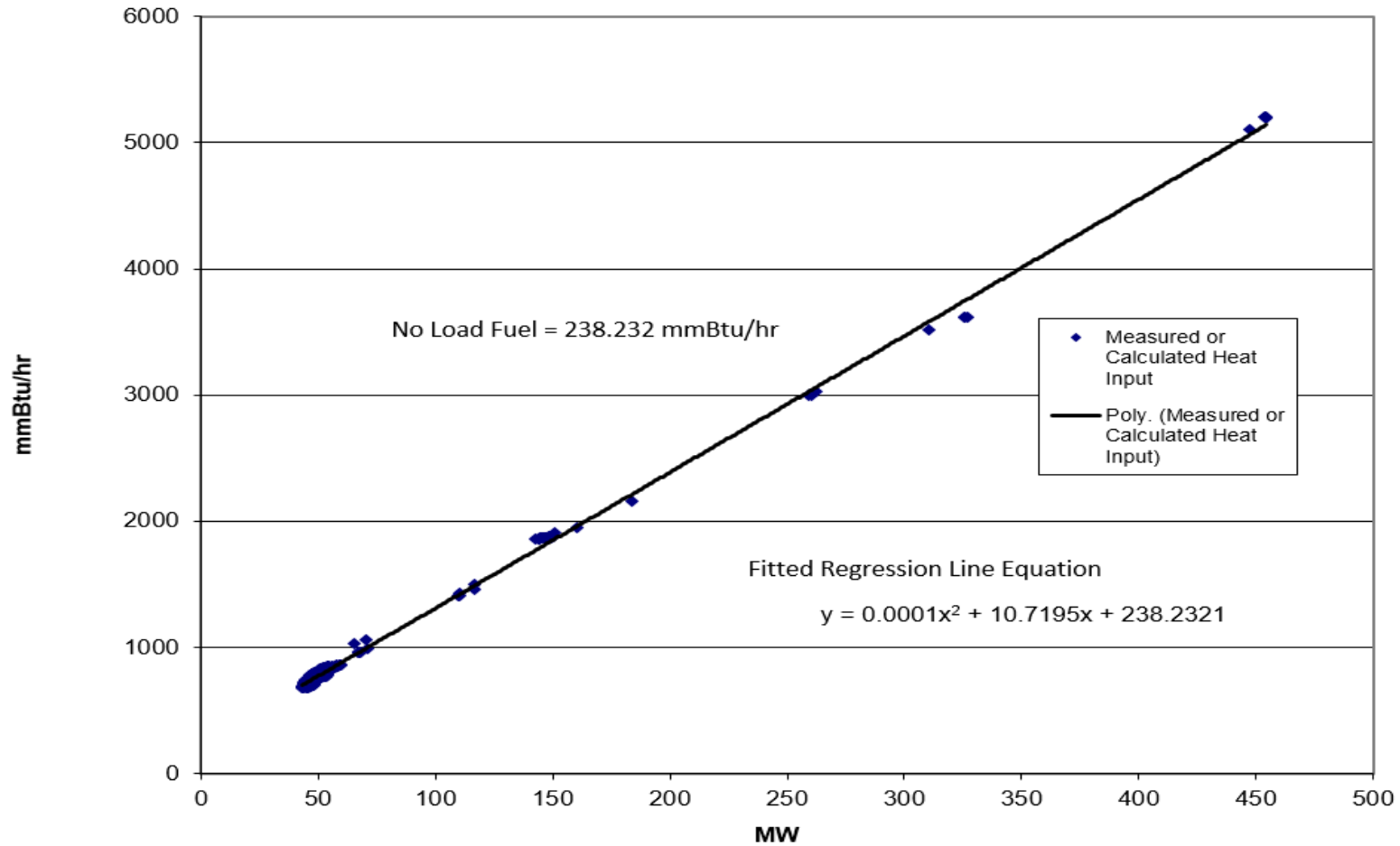
Maintenance Factor is equal to 1 for base load and below and equal to (4-1) for peak firing step



- Manual 15 Attachment H Section B.4 provides a similar example for a 2x1 combined cycle with duct firing

- Cost Offers always start with a heat input curve
- When developing heat input curves
 - Try to maximize the number of data points
 - Use steady state operation data
 - Remove obvious bad data

Typical Natural Gas Heat Input Output Curve
for 550 MW Steam Unit
from Plant Instrumentation Data



Typical Natural Gas Heat Input Output Curve
for 550 MW Steam Unit
from Plant Instrumentation Data

