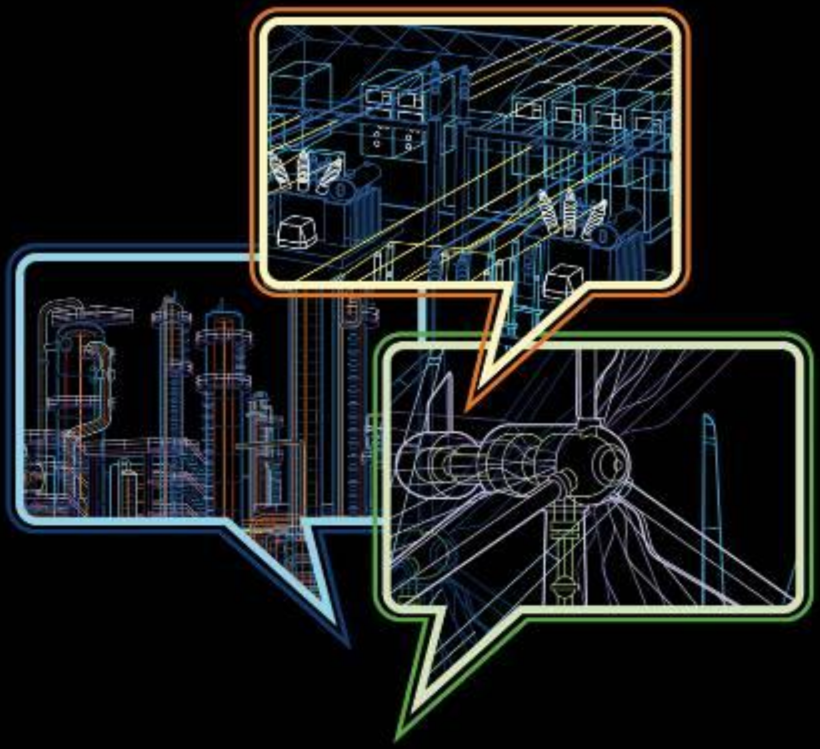


ABB Automation & Power World: April 18-21, 2011

WRE-111-1
Optimal transformer selection for renewable energy

WRE-111-1
Optimal transformer selection for renewable energy

- Speaker name: Michael J. Engel
- Speaker title: Industrial Market Manager
- Company name: ABB Transformers NAM
- Location: Raleigh, NC

Co-presenter

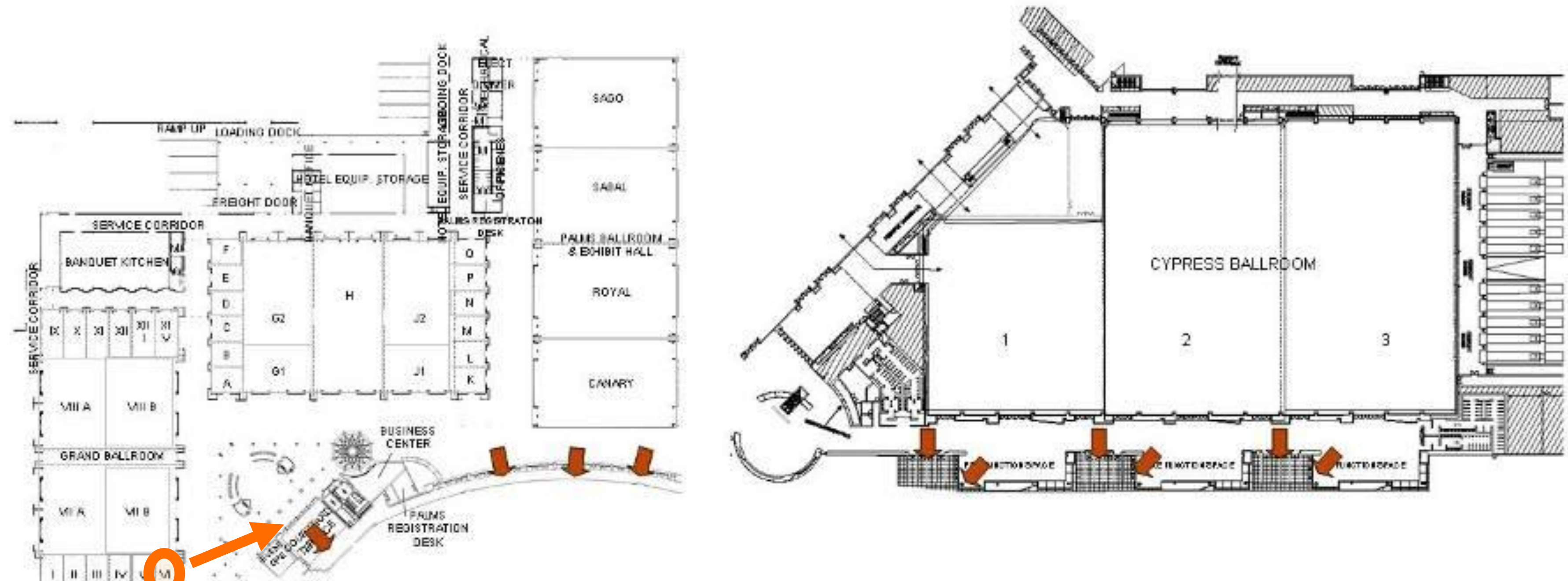
- Speaker name: Doug Getson
- Speaker title: Global Product Manager
- Company name: ABB Transformers
- Location: Jefferson City, MO

Safety first

Your safety is important to us
Please be aware of these emergency procedures

- In the event of an emergency please dial ext. 55555 from any house phone. Do not dial 9-1-1.
- In the event of an alarm, please proceed carefully to the nearest exit. Emergency exits are clearly marked throughout the hotel and convention center.
- Use the stairwells to evacuate the building and do not attempt to use the elevators.
- Hotel associates will be located throughout the public space to assist in directing guests toward the closest exit.
- Any guest requiring assistance during an evacuation should dial “0” from any house phone and notify the operator of their location.
- Do not re-enter the building until advised by hotel personnel or an “all clear” announcement is made.

Your safety is important to us
Convention Center exits in case of an emergency



Know your surroundings:

- Identify the meeting room your workshop is being held in
- Locate the nearest exit

Agenda

Optimal transformer selection for renewable energy

Optimal transformer selection for renewable energy
Agenda

- Transformers applications in renewable energy
- Transformer efficiency
- Transformer solutions for renewable energy
- Wind power case study
- Summary

Optimal transformer selection for renewable energy
Agenda

- Transformers applications in renewable energy
- Transformer efficiency
- Transformer solutions for renewable energy
- Wind power case study
- Summary

ABB transformers in wind power applications

- **GSU Transformers**
- **Grounding Transformers**

Power Transformers
For Collector Systems

Dry type transformers for wind power applications
Special designs for the Nacelle

- Located in the Nacelle
  - Up to 4500 KVA Transformer
  - Cooperating in Prototypes up to 6000 KVA
- Can be located in the Tower
  - Core and Coil Assembly or Complete Transformer

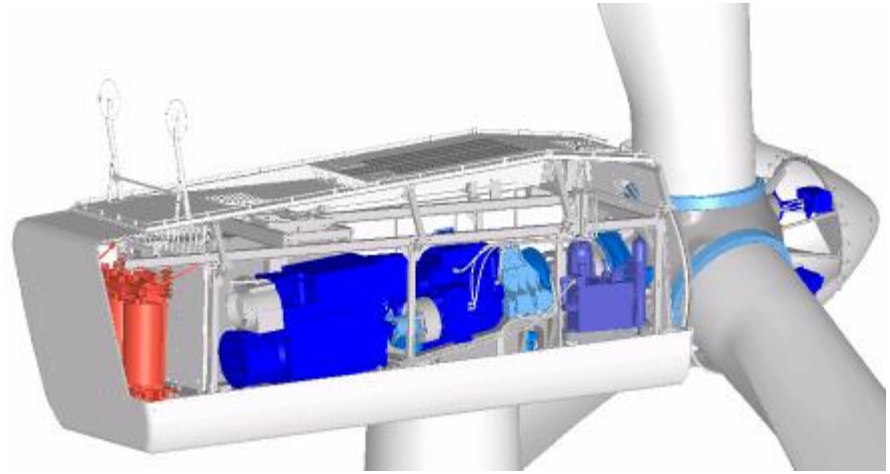
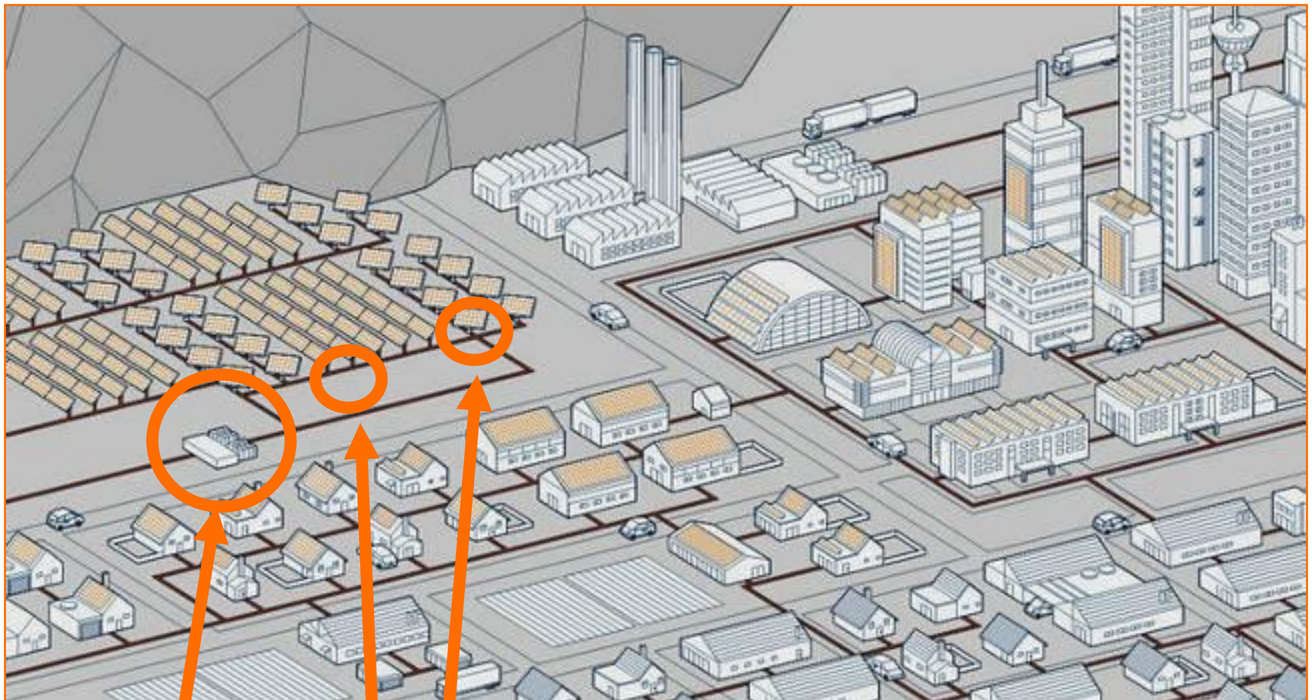


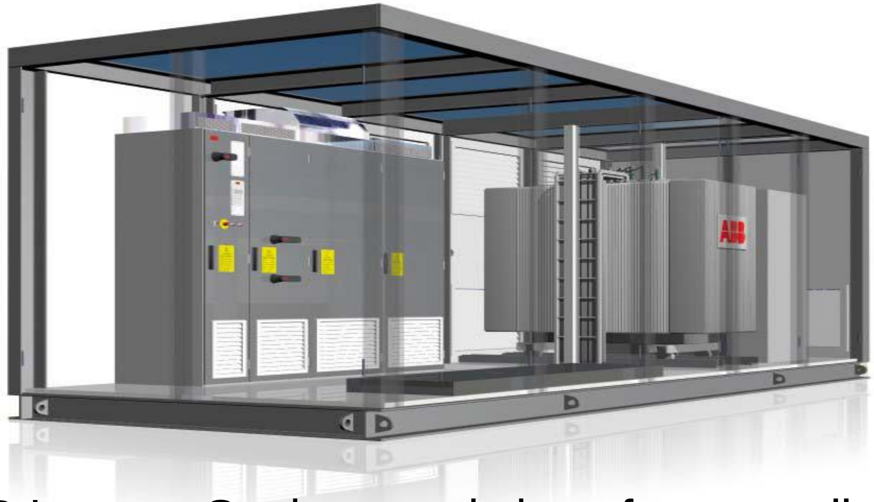
ABB transformers for solar power applications



GSU Transformers

Power Transformers for Collector Systems

Solar inverter / transformer skid assembly



- ABB Inverter Station consisting of two parallel connected ABB inverters, MV transformer and switchgear

Optimal transformer selection for renewable energy
Agenda

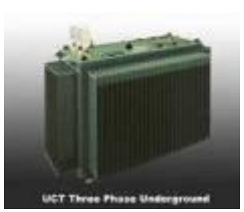
- Transformers applications in renewable energy
- Transformer efficiency
- Transformer solutions for renewable energy
- Wind power case study
- Summary

Transformer efficiency
Definition

- Real cost of a transformer is the sum of the initial purchase price plus cost of running it for its useful life 20-30 years
- Distribution transformers are very efficient (+98%) but will use some energy internally to function

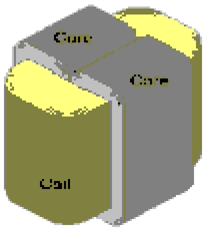
$$\%Efficiency = \frac{(L \times kVA \times PF) \times 10^5}{(L \times kVA \times PF \times 10^3) + NL + (LL \times L^2)}$$

Variables: L = per unit load, kVA = nameplate rating, PF = power factor,
NL = No Load losses, LL = Load Losses



- Owners and operators should consider this when specifying and evaluating transformer purchases
- Total ownership cost will be more than the purchase price

Optimal transformer design
Types of losses



Hysterisis *being the reorientation of the magnetic moments taking place 60 times per second.*

Eddy Currents *flow perpendicular to the flux but broken up by laminating the core and adding silicon increasing resistivity*

- Efficiency reduced by <u>no-load</u> (NL) and <u>load</u> (LL) losses
  - NL losses are caused by the core when energized
    - Hysteresis Losses - chemistry, coating, processing
    - Eddy Current Losses – laminate thickness
  - LL losses are caused by the windings when loaded
    - I^2R Loss - material (CU vs. AL), size and length
    - Eddy Loss - geometry, proximity to steel parts
    - Proportional to the loading on the transformer

Transformer ownership cost
Capitalizing cost of transformer losses

Definition:
Capitalization takes future operating cost of a unit over its lifetime brought back into present day cost to be added to its purchase price to arrive at Transformer Ownership Cost or TOC

Result:
Lower losses result in a cost avoidance derived from the elimination or deferral of generation and T&D capacity additions

- **TOC or Capitalized Cost = Price + Cost of Losses**
  - Price ($) = purchase price
  - Cost of Losses = (A x NLL) + (B x LL)
    - A ($/W) = Capitalized Cost of No-Load Losses
    - B ($/W) = Capitalized Cost of Load Losses
    - NLL (W) = No Load Losses
    - LL (W) = Load Losses
  - Note: A & B Factors are unique to each purchaser of transformer even to their respective industry.

Transformers ownership cost
Web calculators

ABB Power and productivity for a better world™

Home | About ABB | **Products & services** | News center | Careers | Investor relations

Offerings A-Z | **ABB Product Guide** | Industries and utilities | Service Guide | Contact Directory

Product Guide > Transformers > **Transformer calculators**

Transformer loss capitalization and total ownership cost calculator

Whether you are trying to select the most optimal design of a transformer based on shortest payback period or looking at the value of losses on a transformer, these tools can help you.

For more information on getting a hand-held Total Ownership Cost sliding ruler calculator, contact the marketing department at ABB in Jefferson City, Missouri, US. See contact information in right margin.

On line calculators

Total Ownerhip Cost (TOC) Calculators

These tools calculate the present value no-load losses ($/watt) and load losses ($/watt) which added to transformer purchase price is total ownership cost over the lifetime of the transformer. Various methods exist for the present value calculation of losses suggesting the following including one uniquely developed for renewable energy projects.

-- **Universal**

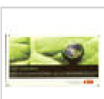
-- **North America (ANSI/IEEE)**

-- **Renewable Energy**

Payback calculator

This tool helps select the most optimal transformer design of two options based on shortest payback period taking into transformer purchase price, losses and cost of energy.

Downloads



Loss capitalization worksheet

This worksheet is to be used in conjunction with a hand-held slide ruler for the calculation of no-load losses ($/watt) and load losses ($/watt). The slider ruler can be ordered by using the "Contact Us" section of this webpage.

www.abb.com/transformers select transformer calculators under highlights

Cost of losses
Capitalization method – renewable energy

- Owner and operator of renewable sites can be either a regulated Utility (UT) or Independent Power Producer (IPP)
- Owner and operators should be optimizing their collector network for the highest return on investment by having the lowest Total Ownership Cost
- Total Ownership Cost (TOC) takes into consideration the negative financial impact losses have on operating the collector network as it reduces kWh sales
- TOC should be ***enhanced*** to include tax considerations and any renewable incentives if applicable.
- Approach to calculating no-load and load loss capitalization differ depending if owner and operator is a UT or IPP.

ABB

Cost of losses
Capitalization method – renewable energy

- **Independent Power Producer** forced to purchase power during hours of no generation and will have its revenue reduced during hours of generation
  - **No-Load loss** capitalization components
    - Demand charge ($/kW) for power purchase cost
    - Energy charge ($/kWh) for power purchase cost
    - Power Purchase Agreement (PPA) revenue lost due to no-load losses when generation greater than zero
    - Corresponding annual escalation of each
  - **Load loss** capitalization component
    - PPA revenue lost due to load losses when generation is greater than zero; PPA annual escalation (if applicable)
    - User of tool have option to enter annual generation profile or capacity factor

Cost of losses
Capitalization method – renewable energy

- **Regulated Utility** forced to replace the losses by planning additional capacity (T&D) and/or generation to deal with collector losses. PPA does not exist as utility sees this as just another source of generation.
  - **No-Load loss** capitalization components
    - System capital investment associated with no-load losses
    - Energy costs associated with no-load losses; annual escalation (if applicable)
  - **Load loss** capitalization component
    - System capital investment to adjust for the difference between network and transformer peak load
    - Energy costs associated load losses; annual escalation (if applicable)
    - User of tool have option to enter annual generation profile or capacity factor

Cost of losses
Web calculators – renewable energy

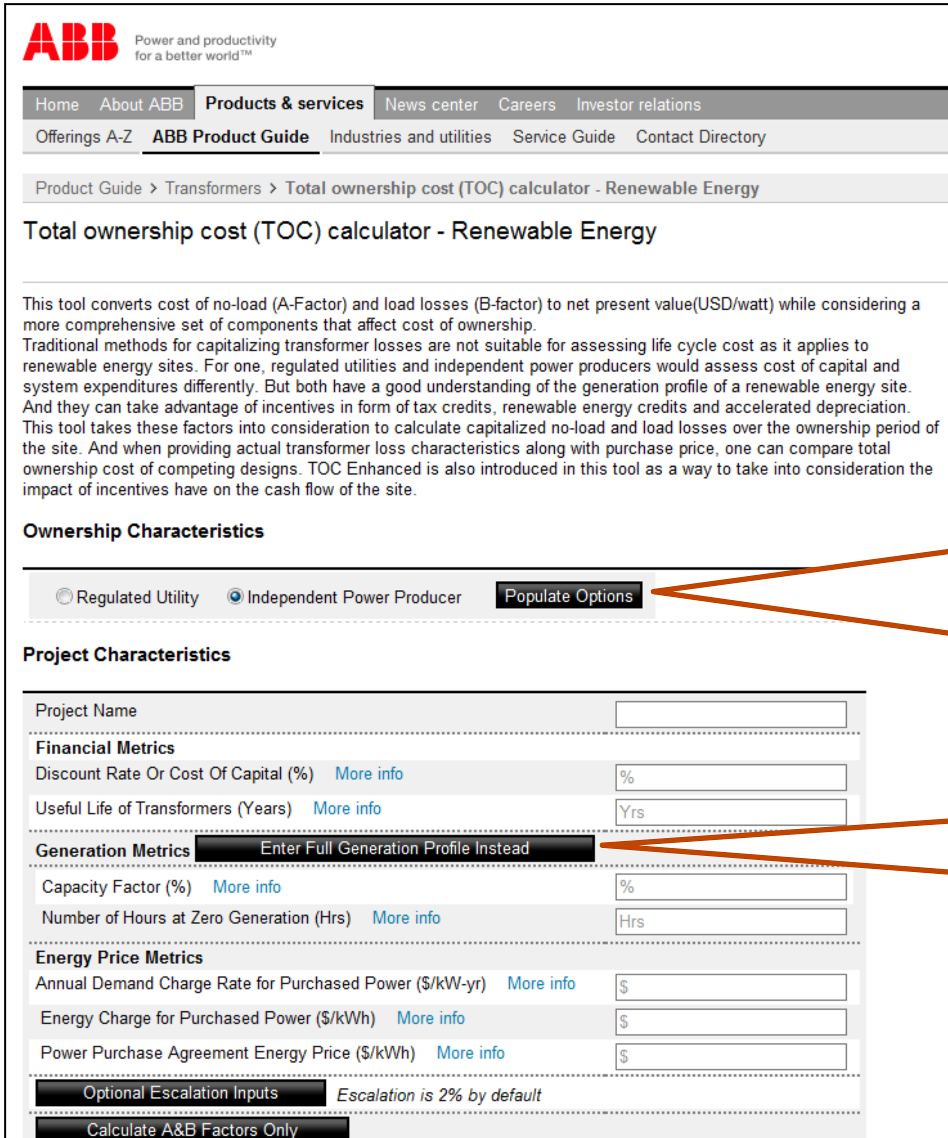


ABB Power and productivity for a better world™

Home | About ABB | **Products & services** | News center | Careers | Investor relations

Offerings A-Z | **ABB Product Guide** | Industries and utilities | Service Guide | Contact Directory

Product Guide > Transformers > **Total ownership cost (TOC) calculator - Renewable Energy**

Total ownership cost (TOC) calculator - Renewable Energy

This tool converts cost of no-load (A-Factor) and load losses (B-factor) to net present value(USD/watt) while considering a more comprehensive set of components that affect cost of ownership.
Traditional methods for capitalizing transformer losses are not suitable for assessing life cycle cost as it applies to renewable energy sites. For one, regulated utilities and independent power producers would assess cost of capital and system expenditures differently. But both have a good understanding of the generation profile of a renewable energy site. And they can take advantage of incentives in form of tax credits, renewable energy credits and accelerated depreciation. This tool takes these factors into consideration to calculate capitalized no-load and load losses over the ownership period of the site. And when providing actual transformer loss characteristics along with purchase price, one can compare total ownership cost of competing designs. TOC Enhanced is also introduced in this tool as a way to take into consideration the impact of incentives have on the cash flow of the site.

Ownership Characteristics

○ Regulated Utility ◉ Independent Power Producer [Populate Options]

Project Characteristics

Project Name		
Financial Metrics		
Discount Rate Or Cost Of Capital (%)	More info	%
Useful Life of Transformers (Years)	More info	Yrs
Generation Metrics	Enter Full Generation Profile Instead	
Capacity Factor (%)	More info	%
Number of Hours at Zero Generation (Hrs)	More info	Hrs
Energy Price Metrics		
Annual Demand Charge Rate for Purchased Power ($/kW-yr)	More info	$
Energy Charge for Purchased Power ($/kWh)	More info	$
Power Purchase Agreement Energy Price ($/kWh)	More info	$

[Optional Escalation Inputs] *Escalation is 2% by default*

[Calculate A&B Factors Only]

Start by selecting if a ***Regulated Utility*** or ***Public Power Producer*** as treatment of financial metrics (e.g. fixed charge rate) and energy price metrics (e.g. demand and energy charge rate) differ

Option to enter ***annual generation profile*** (hours at % generation output) or just ***capacity factor*** (average annual %output)

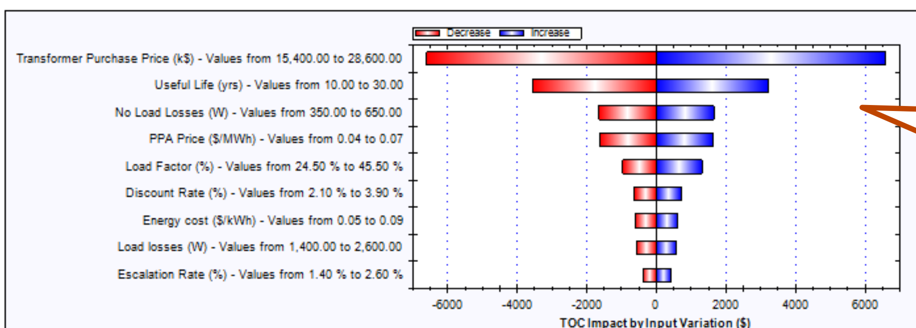
Cost of losses
Web calculators – renewable energy

TOC Calculation Results

Project Name	ABC		Difference (A - B)	% Differ
Transformer	Transformer A	Transformer B		
Transformer Characteristics	Change Inputs	Change Inputs		
Transformer Purchase Price	$ 22,000.00	$ 20,000.00	$ 2,000.00	
No Load Loss (W)	500.00	900.00	-400.00	
Annual No Load Losses(W-hr)	4,380,000.00	7,884,000.00	-3,504,000.00	
Load Loss @ 100%(W)	2000	1850	150.00	
Annual Load Losses (W-hr)	2,146,200.00	1,985,235.00	160,965.00	
Results				
A Factor (No-Load	11.05	11.05		
B Factor (Load $/Watt)	0.95	0.95		
TOC	$ 29,428.73	$ 31,707.24	$ -2,278.51	
TOC Enhanced*	$ 24,520.00	$ 25,662.67	$ -1,142.67	

Show TOC Enhanced Tornado Chart

TOC Tornado Chart



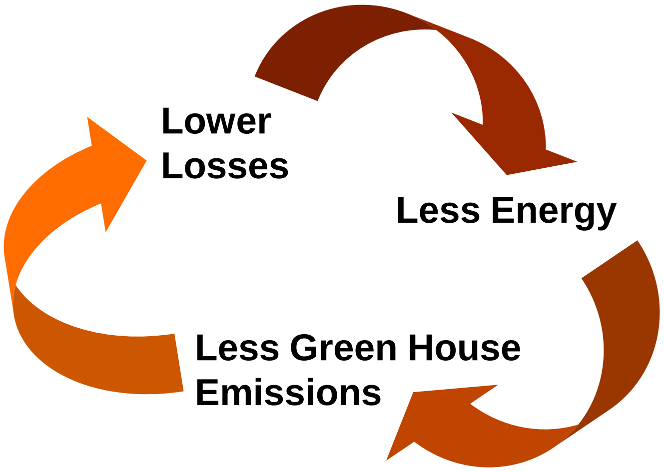
TOC Enhanced accounts for the impact of renewable energy credits, production or investment tax credits, and depreciation on life cycle cash flow

Tornado Chart displaying metrics most impacting Total Ownership Cost (TOC) and allows changes to metric sensitivity (default +/- 30%)

Optimal transformer selection for renewable energy
Agenda

- Transformers applications in renewable energy
- Transformer efficiency
- Transformer solutions for renewable energy
- Wind power case study
- Summary

Amorphous metal distribution transformers
Benefits



2% of all electricity generated is lost due to distribution transformer inefficiency

- Energy savings and lower emissions
  - No-load losses 40-70% lower
  - Efficiency higher by 0.5 - 1.0%
- Lower Total Ownership Cost (TOC) continuously, guaranteed energy savings from the moment of installation
- Meet growing electrical demand with less generation asset investment
- Less heat generation due to lower losses, increases life of transformer insulation
- Savings that doesn't require end customer to change behavior or sacrifice comfort

BIOTEMP® – ABB sensible solution
Unique features

- BIOTEMP® is a superior natural ester fluid made out of sunflower seeds combining…
  - 99% biodegradability with non hazardous and non toxic waste
  - High fire point, i.e., 360°C vs. 180°C for mineral oil
  - Much greater ability to hold moisture, i.e., 10 times more than mineral oil
- Highest oxidation stability for a vegetable-based insulating fluid, outperforming the competition in all standard oxidation stability tests currently available

- With BIOTEMP®, ABB aims at offering a complete and sustainable solution for distribution and power transformers associating environmental friendliness (biodegradability), safety (superior fire resistance), reliability (longer lifetime) and efficiency (higher overload capacity)

BIOTEMP® – ABB sensible solution
Comparative table

Property		Mineral Oil	**BIOTEMP®**	Synthetic Ester	HTH	Silicone
Specific Gravity (g/ml)		0.91	**0.91**	0.97	0.87	0.96
Flash Point (ºC)		160	**340**	275	285	300
Fire Point (ºC)		180	**360**	322	308	330
Pour Point (ºC)		-40	**-15 to -20**	-60	-24	-55
Viscosity (cSt)	@ 100ºC	3	**9**	6	12	16
	@ 40ºC	12	**42**	29	110	38
	@ 0ºC	76	**276**	280	2,200	90
Breakdown Strength (kV) (ASTM D 877)		50	**52**	*> 75**	40	43
Power Factor (%) @ 25ºC		≤ 0.05	**0.09**	0.10	0.01	0.01
Relative Permittivity (-)		2.2	**3.1**	3.2	2.2	2.7
Volume Resistivity (Ω.cm)		10^{15}	**1.5×10^{13}**	*$> 5 \times 10^{13}$**	10^{14}	10^{14}
Biodegradability (%) (CEC L-33-A-93)		30	**97 to 99**	80	20	5

**Not measured according to the same Standard methods*

Partnership in a sustainable environment
Green-R-Pad Distribution transformers

As world population will most likely reach 6-9 billion by 2050, we need to find ways to consume Earth's resources at a rate at which they can be replenished.

- Amorphous Metal lowers ownership cost across entire network from generation, transmission and generation
- BIOTEMP® & Amorphous metal helps reduce greenhouse gases along with pollutants
- BIOTEMP® & Amorphous reduces dependency on foreign oil reserves
- BIOTEMP® is engineered to be environmentally friendly

ABB

Ester-filled transformer product offering
Current product offering

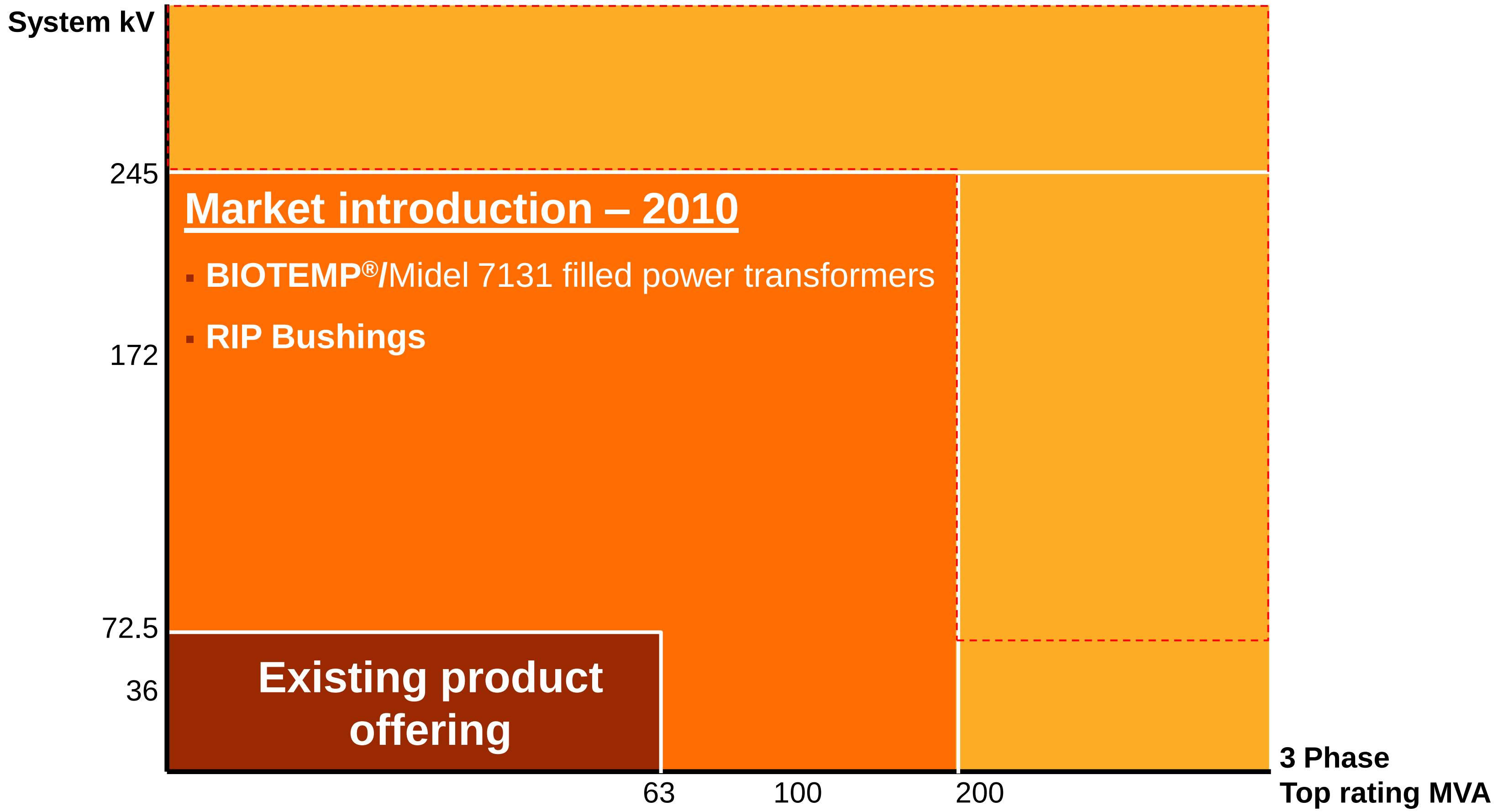


ABB pad mount solutions
Elastimold MVI molded vacuum fault interrupters

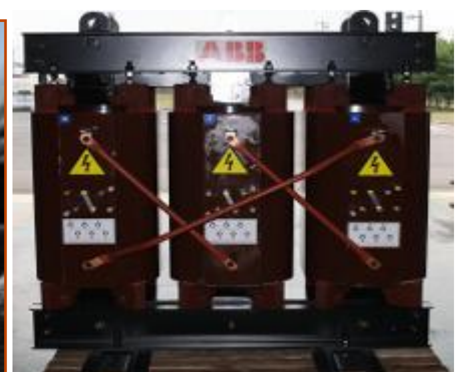
- Interrupt currents through 25,000A
- Adapts 5 to 38KV distribution systems
- Combines Vacuum Interrupters, Programmable, Electronic, Self powered controls
- Field Programmable with wide range of Time-Current Characteristics, Curves and trip settings
- Enable radial or loop feeders to be reconfigured either manually or via SCADA

ABB pad mount solutions
Pad-mount with ABB VersaRupter switch

- Visible disconnect switch
- Break switch outside of HV compartment
- Manual or SCADA operation
- 5 – 38kV
- 600 – 1200A
- 38kV @ 600A

ABB Dry type transformer solutions
EcoDry transformer

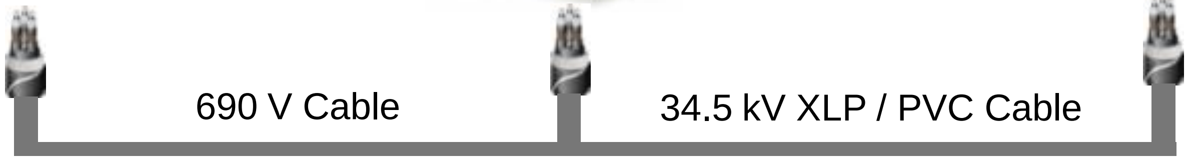
- with no-load loss up to 70% lower than standard dry-type transformers
- initial product range: 100-1600 kVA; up to 36 kV
- No fire hazards – self extinguishing
- Safe and environmentally friendly – no fluids to leak



Optimal transformer selection for renewable energy
Agenda

- Transformers applications in renewable energy
- Transformer efficiency
- Transformer solutions for renewable energy
- Wind power case study
- Summary

Wind Energy case study
Collector major electrical equipment



2.3 MW Turbines
70 at $1.5 M/MW
$242 MUSD

2600 kVA Txfmr
70 at $32k each
$2.24 MUSD

100 MVA Txfmr
34.5:230 kV
$1.35 MUSD

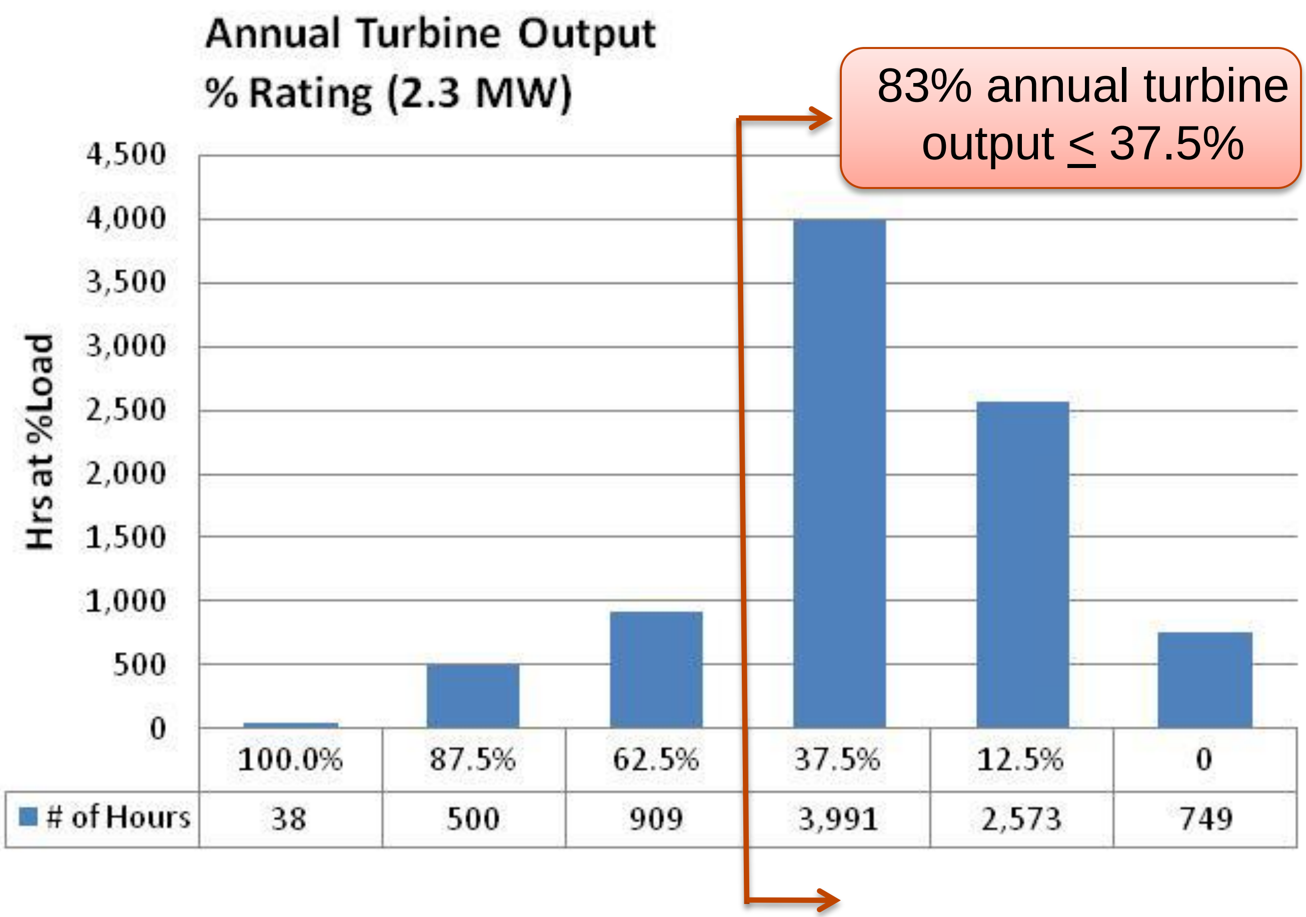
Wind Energy case study
Outcome

- **$250M equipment investment for 160 MW wind site**
  - 70 - 2.3 MW turbines
  - 70 - 2600 kVA 690V:34.5kV padmount transformers
  - 1 -100 MVA 34.5:230kV substation transformer
  - 530 thousand feet - XLP underground cable

- $**450k incremental capital cost for higher efficiency pads**
  - $125k (1,842 MWh) additional annual energy sales
  - Assumption - 30% Income Tax Credit (ITC)
  - Assumption - 20 yr Power Purchase Agreement (PPA)
  - **25% IRR** and **less than 3 year payback** on investment

Wind Energy case study
Generation profile

- Base case generation profile based on actual wind site in the United States
- 83% generation hours at or less than 37.5% of generation capacity
- It's been reported that most wind sites operate on average at less than 50% of capacity during the year



Wind Energy case study
Core material impact

- Amorphous cores have lower no-load (NL) losses by up 70% than grain oriented
- NL Base Cases
  - GO 3,900 W
  - AM 745 W
- %Efficiency (LF 1.0)
  - RGO 99.06%
  - AM 99.13%
- No-load losses are made up of hysteresis (reorientation of magnetic moments 60 times/sec) and eddy currents (flow perpendicular to the flux broken up by laminating)

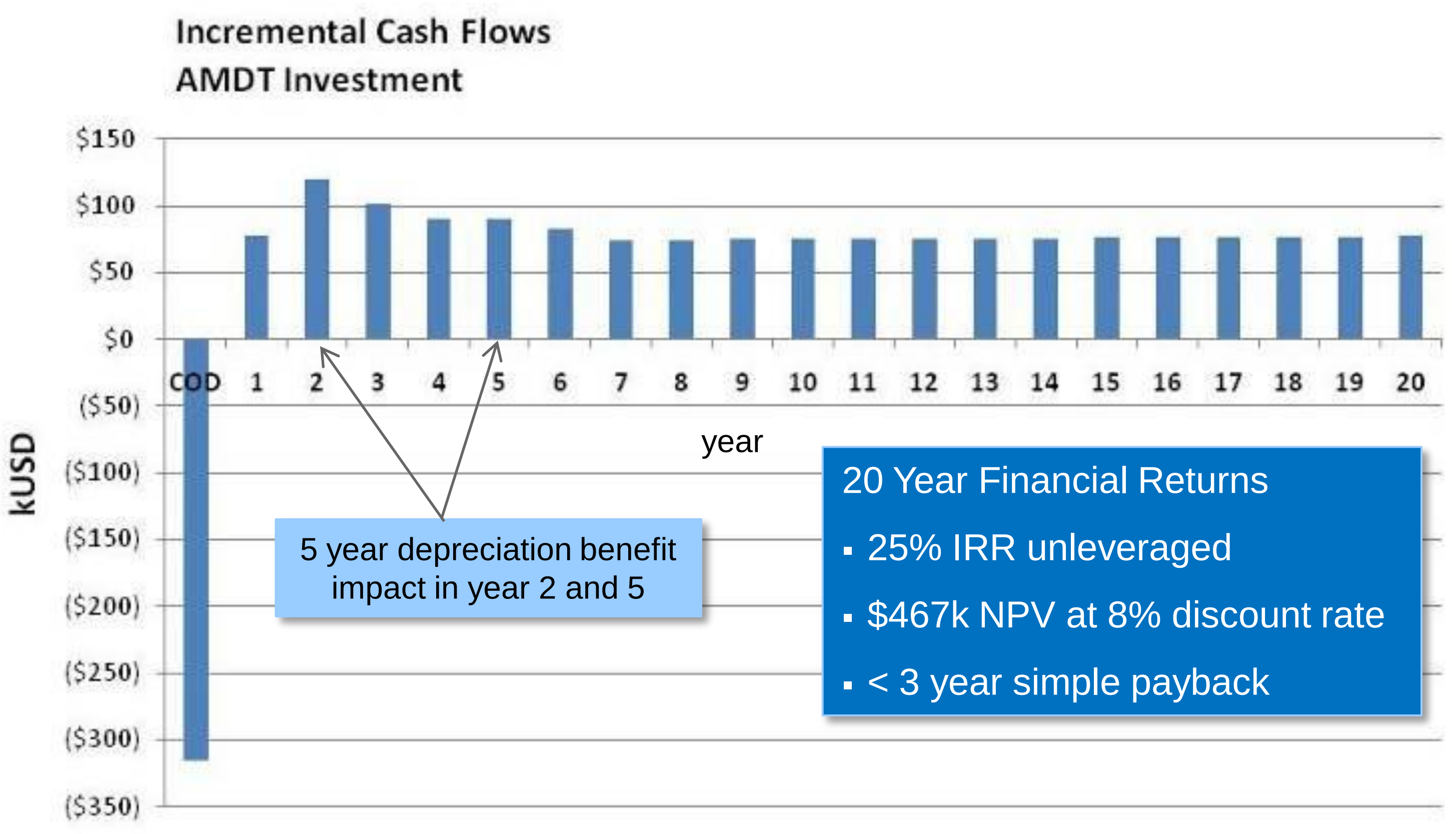
Turbine Output	Grain Oriented		Amorphous	
	Energy Sales (MWh)	Losses	Losses	Energy Sales (MWh)
100.0%	5,880	3.25%	3.17%	5,885
87.5%	68,386	2.91%	2.81%	68,462
62.5%	88,837	2.87%	2.68%	89,008
37.5%	234,890	2.52%	2.17%	235,736
12.5%	50,113	3.22%	2.11%	50,690
0.0%	-208	0.00%	0.00%	-39
	447,899	2.78%	2.38%	449,741

GO MWh < AM MWh sold

Wind Energy case study
Incremental cash flow

Base Case:

- 30% ITC
- 20 year PPA
- $70 / MWh PPA levelized
- $50 / MWh demand charge levelized
- $450k incremental capital cost on Commercial Operation Date (COD)
- Capital cost offset by 30% ITC
- Year 1 income stream starts in May (8 months)



Note: Financial analysis completed by Competitive Energy Insight, Inc., San Diego, CA

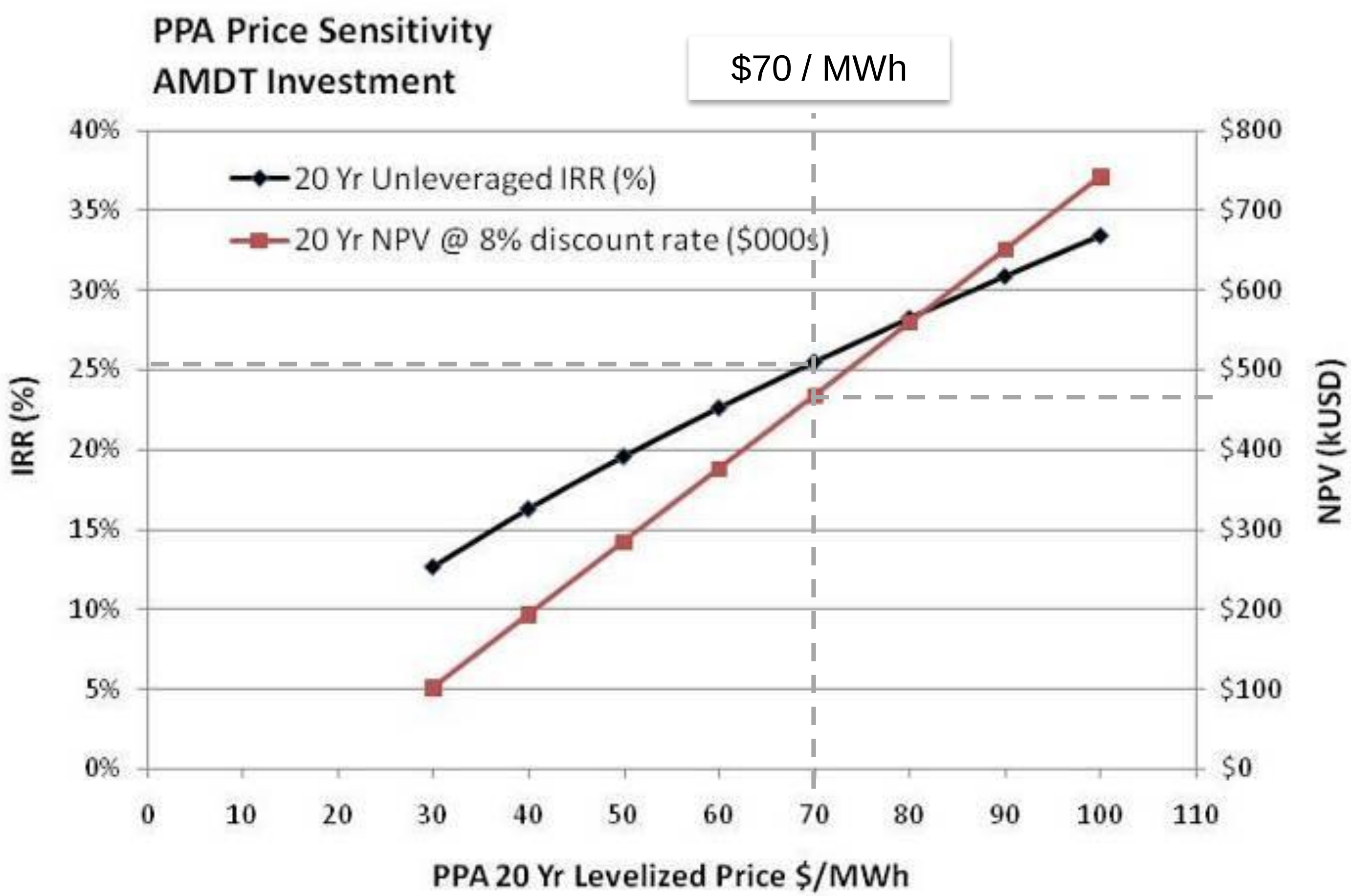
Wind Energy case study
PPA price sensitivity

Base Case

- Capacity factor
- Generation Profile
- Average energy price
- ITC vs. PTC
- Unleveraged or zero debt investment

Not Considered

- Time-of-Day energy pricing
- Escalation
- P99 debt sizing
- Discount rate
- Transaction structure



Note: Financial analysis completed by Competitive Energy Insight, Inc., San Diego, CA

Wind Energy case study
Generation sensitivity

Generation Profile - Sensitivities	**Base Case (AM)**	**Base Profile 1**	**Base Profile 2**	**Base Profile 3**	**Base Profile 4**	**Base Profile 5**
20 Year Unleveraged IRR %	25.5%	23.7%	24.3%	24.6%	25.4%	25.3%
20 Year NPV @ 8% Discount (kUSD)	$467	$409	$428	$437	$465	$461
Simple Payback (Years)	<3	<3	<3	<3	<3	<3

- Varying generation outputs does not dramatically change financials
- Low no-load loss (amorphous) is still a good investment even at generator outputs that average 75% of nameplate
- IRR remains > 23% with < 3 year payback on investment

Generation profiles very by amount of time (hours) each certain turbine outputs (MW)

Optimal transformer selection for renewable energy
Agenda

- Transformers applications in renewable energy
- Transformer efficiency
- Transformer solutions for renewable energy
- Wind power case study
- Summary

Green transformer program
Green-R-Trafo™ / EcoDry™

- **Environmentally sensitive solutions**
  - 40-70% lower no-load losses reducing ownership cost
  - Higher fire point, longer life and biodegradable insulation
- **Reliable and customer solutions**

  - Conventional and new technologies for lower operating cost
  - Lower losses generate less heat reducing liquid and cooling
  - Tested to meet applicable standards
- **Financial benefits**
  - Payback in as little as 3 years when buying lower total ownership cost
  - Higher efficiency means avoided capital cost in T&D infrastructure to keep up with energy demands

Questions?

Reminders
Automation & Power World 2011

- Please be sure to complete the workshop evaluation
- Professional Development Hours (PDHs) and Continuing Education Credits (CEUs):
  - You will receive a link via e-mail to print certificates for all the workshops you have attended during Automation & Power World 2011.
  - BE SURE YOU HAVE YOUR BADGE SCANNED for each workshop you attend. If you do not have your badge scanned you will not be able to obtain PDHs or CEUs.

Power and productivity
for a better world™

ABB