SDT JCity Version, October 2009

# Benefits of Distribution Transformer Efficiency Beyond DOE National Efficiency Standards

# Benefits of Distribution Transformer Efficiency Beyond DOE National Efficiency Standards

- **Introduction**
- US National Efficiency Standards
- Transformer Efficiency Basics
- Transformer Loss Evaluation
- ABB Green-R-Pad™ Sustainability Solution
- Amorphous Metal Technology
- BIOTEMP® Natural Ester Fluid

# Introduction
## Global responsibility

- **Sustainability** is the responsibility that we all have in balancing the economic needs of society with social and environmental impact.
- WWF defines it as *improving the quality of human life while living within the carrying capacity of the eco-systems.*

- Global $CO_2$ emissions up to 30 Giga Tons per year
  - Pre-industrial atmospheric levels 280 parts per million
  - 2005 up 35% to 379 parts per million
- Global acceptance that cheap and plentiful energy is a thing of the past and that growing demand is harming the environment and quality of life

# Introduction
## Our every day necessities…

- Ever growing population
- Energy consumption to double within 30 years
- Sustaining a power-hungry world
- Concern about climate change
- Ensuring a reliable grid
- Providing energy efficient products and solutions
- Investing in the future

More than ever, the need for energy efficient products and reliable grids will grow.

# Introduction
## Distribution transformers

- Losses in distribution transformers represent a considerable part of the total distribution losses
- High potential to save energy by installing low loss transformers for new construction
- Even higher energy savings by replacing old high loss transformers by new low loss designs
- These savings can start now even with existing technology

# Benefits of Distribution Transformer Efficiency Beyond DOE National Efficiency Standards

- Introduction
- **US National Efficiency Standards**
- Transformer Efficiency Basics
- Transformer Loss Evaluation
- ABB Green-R-Pad™ Sustainability Solution
- Amorphous Metal Technology
- BIOTEMP® Natural Ester Fluid

# The National Efficiency Standards
# Historical Timeline

- **Energy Policy and Conservation Act (EPCA) of 1975**
  - Efficiency standards "shall be designed to achieve that maximum improvement in energy efficiency".
  - Empowers determination of energy efficiency stds.
  - Energy conservation for major household appliances
- **National Energy Conservation Act of 1978**
  - Amended EPCA establishing an energy conservation program for certain industrial equipment
- **Energy Policy and Conservation Act (EPACT) of 1992**
  - Amended EPCA establishing an energy conservation program for certain commercial equipment, including distribution transformers
  - Oak Ridge National Laboratory technology study

# The National Efficiency Standards
## Historical Timeline

- **1997 Notice of Determination**
  - Technology feasibility
  - Economically justifiable
  - Significant energy savings
- **2007 Final Rule Distribution Txfmrs (72 CFR 58190)**
  - Domestic and Imported production of Liquid & Dry Distribution Transformers
  - Manufactured in or imported into the United States and its territories on or after **Jan 1, 2010**
  - 60 Hz, ≤ 34.5 kV Input & ≤ 600 V Output
  - Ratings 1Φ - 10 to 833 & 3Φ - 15 to 2500 kVA
  - Re-builders exempt unless found circumventing standard
  - Inventories manufactured before start date exempt

# The National Efficiency Standards
## Lawsuit Settlement

- **Petitioners - Sierra Club, Natural Resource Defense Council, Earthjustice & various states**
- **Petition to consider certain factors when considering economic justification:**
  - Employment impact
  - Value of reduced carbon dioxide emissions
  - Impacts on the price of energy
- **Settlement to dismiss petition contingent on…**
  1. Review of standards <u>no</u> later than Oct 1, 2011 for those economic justification factors
  2. If amendment justified, DOE shall publish no later than Oct 1, 2012 a final rule.
  3. Industry compliance no later than Jan 1, 2016

# Benefits of Distribution Transformer Efficiency Beyond DOE National Efficiency Standards

- Introduction
- US National Efficiency Standards
- **Transformer Efficiency Basics**
- Transformer Loss Evaluation
- ABB Green-R-Pad™ Sustainability Solution
- Amorphous Metal Technology
- BIOTEMP® Natural Ester Fluid

# Introduction
## How much does a distribution transformer really cost?

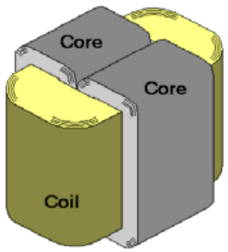

- Real cost of a transformer is the sum of the initial purchase price plus cost of running it for its useful life 20-30 years
- Distribution transformers are very efficient (+98%) but will use  some energy internally to function


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

*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
- Life cycle cost will be more than the purchase price

# Introduction
## How much does a distribution transformer really cost?




***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 impacted by No-load (NL) and Load (LL) Losses
  - NL generated by core losses and is immediate upon energizing the transformer
    - Hysteresis Losses - chemistry, coating, processing
    - Eddy Current Losses – laminate thickness
  - LL is generated by the winding losses while being 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

# Introduction
## How much does a distribution transformer really cost?

- Transformer designers can alter the design to provide a solution with reduced no-load, load losses or both.
  - Improvement in performance requires in most cases a more expensive transformer with possibly a larger footprint
  - A trade off is required between high efficiency (high initial cost) and life cycle cost savings (loss evaluation) when improving transformer efficiency

| Ways to Reduce No-Load Loss | Ways to Reduce Load Loss |
|---|---|
| Use better grade of core material | Use copper rather than aluminum |
| Use thinner core steel laminations | Use a conductor with a larger area |
| Use more turns in the coil | Use fewer turns in the coil |
| Use a core with larger leg area | |

# Benefits of Distribution Transformer Efficiency Beyond DOE National Efficiency Standards

- Introduction
- US National Efficiency Standards
- Transformer Efficiency Basics
- **Transformer Loss Evaluation**
- ABB Green-R-Pad™ Sustainability Solution
- Amorphous Metal Technology
- BIOTEMP® Natural Ester Fluid

# Transformer Loss Evaluation
# Terminology

- Total Ownership Cost (TOC)
  - All life cycle costs are considered from purchase price to commissioning to maintenance costs; even emissions depending on regulations; but primary cost drivers are purchase price, loss of revenue and capital investment.
- Loss Evaluation Formula
  - Means by which purchaser uses to evaluates varying options for the same transformer rating and application of transformer
  - Purchaser established factors (A & B) penalizing higher loss designs as they lead to higher ownership cost
- Capitalization Formula
  - When talking TOC we're actually capitalizing or converting cost of losses (A & B) to net present value and adding them to the purchase price

# Transformer Loss Evaluation
## Loss Evaluation Formula

- **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
  - A & B Factors are unique to each purchaser of transformer even to their respective industry as we will seen here in a minute

# Transformer Loss Evaluation
## No-Load & Load

- **No-Load Losses**
  - Totally independent of transformer loading and are present 100% of the time when the transformer is energized
  - Grade and type of core material can have a dramatic impact with Amorphous metal offering the lowest possible losses in today's technology
  - Reduced flux density (T) also reduces core losses
- **Load Losses**
  - Directly dependent on transformer loading
  - Varies by the square of the load current
  - Affected by conductor material and cross sectional area
  - For liquid filled transformers, specify at 20°C rise

Higher grades and increased quantity of materials will lead to higher purchase prices but lower total ownership cost

# What factors influence capitalized cost?
## A & B Factors

- Annual time in operation (energized)
  - 8760 hrs normally for a Distribution Transformer

- Relative transformer load factor
  - Can be specified as average power in relation to max power or in percentage of max power

- Anticipated economical life time in operation
  - Normally >20 years
  - ABB Distribution Transformers are designed and materials chosen to withstand more than 30 years under normal operating conditions

# What factors influence capitalized cost?
## A & B Factors

- Cost of Energy
  - Average cost of energy during the life time in operation
  - For Utilities, it's best represented by loss of revenue

- Interest rate for calculating net present value factor over the life time of the transformer in operation

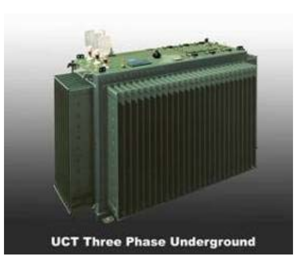
| Interest | 10 yrs | 20 yrs | 30 yrs |
|---|---|---|---|
| 4% | 8.1 | 13.6 | 17.3 |
| 6% | 7.4 | 11.8 | 13.8 |
| 8% | 6.7 | 9.8 | 11.3 |
| 10% | 6.1 | 8.5 | 9.4 |

# Benefits of Distribution Transformer Efficiency Beyond DOE National Efficiency Standards

- Introduction
- US National Efficiency Standards
- Transformer Efficiency Basics
- Transformer Loss Evaluation
- **ABB Green-R-Pad™ Sustainability Solution**
- Amorphous Metal Technology
- BIOTEMP® Natural Ester Fluid

# ABB's Commitment
# Contribute to a Greener future through partnership



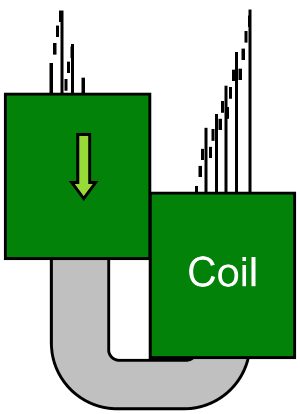



- Providing energy efficient products and solutions supporting and contributing to reduction of $CO_2$ emissions
- Product development based on both conventional and new technologies and solutions
- **Liquid Filled Distribution Transformer** design features and options
  - Conventional technology high efficiency and low loss designs
  - Amorphous Metal (AM) technology for ultra low loss designs
  - BIOTEMP® natural ester insulating fluid
    - Biodegradable, non-toxic and high fire point
  - Water based surface treatment
  - Hermetically sealed solutions

# Benefits of Distribution Transformer Efficiency Beyond DOE National Efficiency Standards

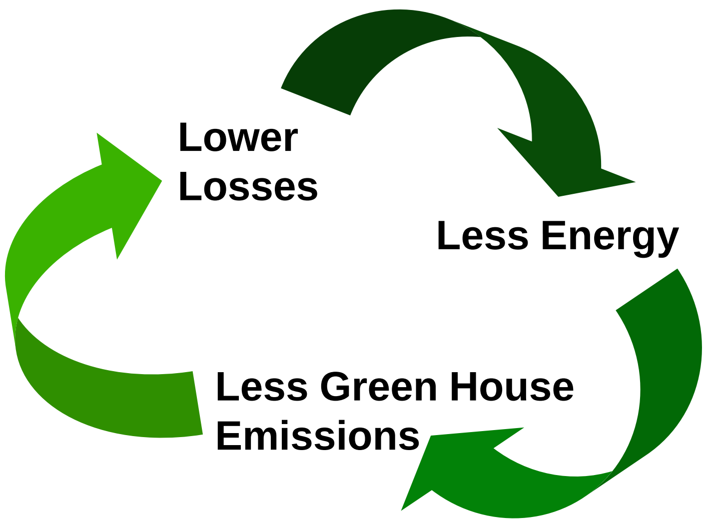
- Introduction
- US National Efficiency Standards
- Transformer Efficiency Basics
- Transformer Loss Evaluation
- ABB Green-R-Pad™ Sustainability Solution
- **Amorphous Metal Technology**
- BIOTEMP® Natural Ester Fluid

# Amorphous Metal Distribution Transformers
# Performance




- Very little differences in production techniques between AM and GO steel wound core transformers, mostly to do with material handling
  - Extensive expertise within ABB in wound core DT technology
- Loss benefits of material being carried over into no-load losses of DTs
  - Efficiency increase by 0.5% to 1%, depending on rating
- Due to lower design inductions and lower space factors than GO steels, AM cores are heavier
- Noise levels in AMDTs are 3 – 5 dB higher than in GO steel DTs, but are below the noise level specifications in global standards
  - Higher noise levels are due to the lack of crystalline structure
- Utility studies over the last two decades have confirmed that AMDTs show no degradation of performance over time

# Amorphous metal distribution transformers
## Customer values




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

(~25 GW of power lost)

- Energy savings and increased efficiency
  - No-load losses 40 - 70% less than GO steel
  - Efficiency + 0.5 - 1.0%, depending on rating
- Lower Total Ownership Cost (TOC)
  - Continuous, guaranteed energy savings from the moment of installation
- Meet growing electrical demand with less generation asset investment
  - Less greenhouse gas emissions
- Less heat generation due to lower losses, favorable impact on aging of insulation
- Savings that doesn't require end customer to change behavior or sacrifice of comfort
- Amorphous material can be reused

# Benefits of Distribution Transformer Efficiency Beyond DOE National Efficiency Standards

- Introduction
- US National Efficiency Standards
- Transformer Efficiency Basics
- Transformer Loss Evaluation
- ABB Green-R-Pad™ Sustainability Solution
- Amorphous Metal Technology
- **BIOTEMP® Natural Ester Fluid**

# Natural ester-based dielectric insulating fluids
## Today's market trend

*ABB units with natural ester-based fluid have been in service since 1999 and has been developing this fluid ever since*

- Ester fluids entered market in the 1980's as an alternative combining excellent fire safety properties with high biodegradability
  - Esters are a broad class of organic compounds chemically synthesized from organic precursors (synthetic esters) or available from agricultural products (**natural esters**)
  - While synthetic esters high cost currently limits their use to specialty applications, natural esters have lately matured into suitable and affordable dielectric insulating fluids

IEEE

**IEEE Guide for Acceptance and Maintenance of Natural Ester Fluids in Transformers**

**IEEE Power & Energy Society**

Sponsored by the
Transformers Committee

UL LISTED

FM APPROVED

- Natural esters are now recognized as environmentally friendly and "less flammable" dielectric insulating fluids
  - ➢ Factory Mutual & and UL listed
  - ➢ Specified by ASTM D 6871, ABNT NBR 15422, IEEE C57.147 & IEC ('10 anticipated)

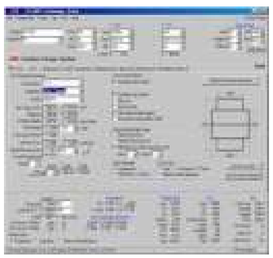
# Summary

- Introduction
- US National Efficiency Standards
- Transformer Efficiency Basics
- Transformer Loss Evaluation
- ABB Green-R-Pad$^{TM}$ Sustainability Solution
- Amorphous Metal Technology
- BIOTEMP® Natural Ester Fluid

# The complete portfolio – ABB value proposition
## Drivers and consequences of higher energy efficiency

$$\eta_{\%} = \frac{100}{1 + \frac{P_0 + P_L \cdot m^2}{P_2 \cdot m}}$$

1. When purchasing transformers, ABB recommends the use of **Total Ownership Cost (TOC)**. In this way the customer/user can obtain a practical balance between investment and reward, reflecting the continuous change in global and local business conditions at any time

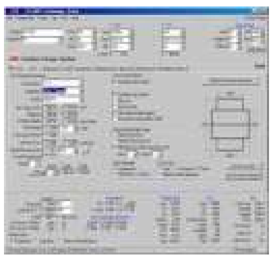


2. Energy saving programs and energy efficiency requirements are today driven both by global and local initiatives

3. Given that a drastic energy reduction is requested to save our global climate, low loss transformers should be chosen on other grounds than pure short term profitability aspects

# The complete portfolio – ABB value proposition
## Drivers and consequences of higher energy efficiency

$$\eta_{\%} = \frac{100}{1 + \frac{P_0 + P_L \cdot m^2}{P_2 \cdot m}}$$



4. ABB can manufacture transformers with considerably lower losses than those which are frequently delivered today. 40 – 70 % loss reductions are easily attainable
5. Low loss transformers have generally higher weight and have larger outside dimensions
6. With new transformers, the higher material cost will be compensated by reduced running costs from lower losses. Beyond a certain time, the lower losses will give a net financial saving from reduced energy costs
7. By replacing old high loss transformers with new low loss transformers, this saving becomes even higher

Power and productivity
for a better world™

ABB