CARBON-ZERO

VERIFIED CARBON ASSESSMENT

Prepared for: H2scan

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Photo by The Hartford Steam Boiler Inspection & Insurance Co.

Based on an average 0.35 to 2.9% transformer failure rate, global transformer replacements could cost

$430 Billion US Dollars.

With 85 Million Tons of associated Carbon Emissions. *

H2scan online hydrogen sensors can reveal potential faults helping prevent transformer failure & avoid these massive costs and carbon emissions!

***Installed Global Base 12 Million, Average 1.625% Failure rate, Average cost $2.1M, Average Tons CO2 emission 438.**

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1. Executive Summary

High Voltage Electric Power Transmission and Distribution Transformers are typically reliable, but age and operational stresses can lead to component degradation resulting in poorer performance and generation of hot spots. These hot spots can result in hydrogen gas generation in the oil and can be an early indication of transformer problems that can lead to failure.

With power transformers having an installed cost range of $0.1M to $10M, this carbon assessment report highlights the high cost and levels of carbon emissions associated with installing a new replacement Electric Power Transmission transformer. It highlights the benefits from installing a low cost H2scan hydrogen online sensor which provides an early warning of transformer problems associated with hydrogen gas generation.

When a transformer prematurely fails from internal component problems it can result in increased hydrogen gas levels leading to breakdown and interruption of supply or at worst explosion.

H2scan's simple low maintenance solution for real time monitoring solutions provide effective continuous online monitoring revealing potential faults, before failure.

2. Background

With over 12 Million Electrical Power Transformers installed around the world delivering power from generation sites to our factories, offices, and homes; our reliance on continuity of supply for production, transport, safety, and comfort is something we all take for granted. The pressure on the transmission companies grows every year with our ever- increasing expectations, the requirement for continuity of supply relies heavily on the continued operation and performance of all elements in the supply chain. Transformers play a significant role in the delivery of electrical power, so their reliability is paramount to continued performance.

The performance of Transformers has long been a major concern for the national electric power sectors because failure of a single unit can cause temporary service interruption and lead to significant collateral damage, and it could be difficult to quickly replace.
Key industry sources have identified the limited availability of spare transformers as a potential issue for critical infrastructure resilience in the United States, and both the public and private sectors have been undertaking a variety of efforts to address this concern.

As process and electrical demands fluctuate and system components occasionally struggle to cope with unexpected changes, it is not surprising when a small percentage of transformers, particularly older units begin to have problems. These can result in internal component degradation, insulation breakdown and can generate temperature rise in the insulating oil contained in most transformers. When transformer oil is subject to excessive temperatures, hydrogen gas precipitates from the oil. These rising hydrogen levels combined with high temperatures and internal arcing can cause significant failure, even explosion in some instances. Scheduled sampling of the oil can provide an indication of hydrogen levels and potential internal problems, however, this relies on manual intervention and sample analysis and will not indicate problems in between sampling.

H2scan sensors are an excellent early warning system and help avoid the expense of costly replacement and importantly, in these current times of global warming, help avoid the large carbon emissions associated with the materials and component manufacture and installation, related to building new transformers.

3. Introduction to Greenhouse Gas Emissions (GHG)

Context

In response to the increased awareness of global warming, countermeasures against greenhouse gas emissions were prepared by the United Nations Conference on Environment and Development (UNCED) at the Rio Earth Summit held in Brazil in 1992. Since then, international efforts have continued to reduce greenhouse gas emissions through the Kyoto Protocol in 1997 and the Copenhagen Accord in 2009. Most Recently, the Paris Climate Agreement was signed which aims to bring all nations into a common cause to undertake more ambitious efforts to combat climate change and adapt to its effects.

Many countries around the world have outlined action plans to reduce greenhouse gas emissions and are preparing policies that include their reduction goals. Among developed countries, examples of reduction goals by the year 2020 include 34% in the UK, 20% in the EU, 17% in the US and 15% in Japan. [1]

Concern over climate change has stimulated interest in estimating the total amount of greenhouse gasses (GHG) produced during the different stages in the —life cycle of goods and services — i.e. their production, processing, transportation, sale, use and disposal. The outcome of these calculations is often referred to as —product carbon footprints (PCFs), where 'carbon footprint' is the total amount of GHGs produced for a given activity and 'product' is any goods or services that are marketed. PCFs are thus distinct from GHG assessments performed at the level of projects, corporations, supply chains, municipalities, nations, or individuals.

Product carbon foot printing is currently dominated by private standards and by certification schemes operated by small for-profit and not-for-profit consultancy companies and in a few cases by large retailers and manufacturers. Government support to PCF schemes and standards has been limited so far. The exceptions are the PAS 2050 standard, the development of which was supported by the UK Department for Environment, Food and Rural Affairs (Defra); Japan's pilot Carbon Footprint Scheme, launched in April 2009; and the assistance provided by the French Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) in the development of a scheme operated by the food retailer Casino. At the international level, PCF standards are being developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD-WRI), through its Greenhouse Gas Protocol; and by the International Office for Standardisation.

[1] Woosik Jang, Hyun-Woo You (2015) *Quantitative Decision-Making Model for Carbon Reduction in Road Construction Projects Using Green Technologies*. Sustainability, 7 (1), pp.11240-11259

[2]Simon Bolwig, Peter Gibbon (2009) *Counting Carbon in the Marketplace*. Global Forum on Trade: Trade and Climate Change, OECD.

4. Objectives

- The objectives of this report are to identify the range of Electrical Power transformer sizes, weight, and materials of construction
- Identify approximate global installed base
- Reasons for transformer failure
- Incidence of failure
- Assess the carbon emissions produced in the manufacture of each size of transformer
- Assess the carbon emissions associated of transport, installation, and disposal of a prematurely failed transformer.
- Tabulate the carbon footprint associated with each transformer size / weight

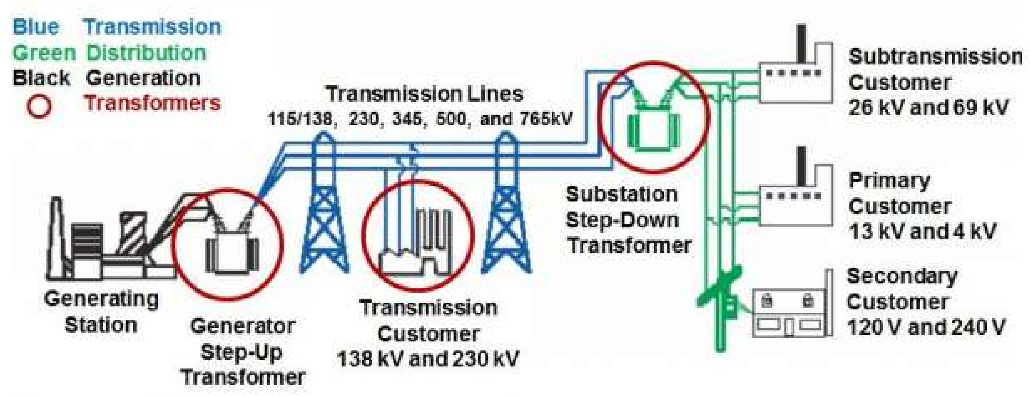
  Exclusions from Scope

  The only element not included in the assessment is the mobilisation of manpower.

5. Transformer Ranges and Installed Base

The range and type of transformers in typical Electricity power transmission grid:

Figure 1. Electric Power Grid Representation



Source: DOE, 2006; see Footnote 14. Modified based on industry review.

Global estimates by Newton Evans total the installed base of Three Phase Transformers at around 12 Million with around 300,000 being produced per year.

6. Cost and weights of transformers ranges

Estimated Cost and weights of 1-750 MVA Transformers			
Voltage Rating (Primary-Secondary)	Capability MVA Rating	Weight Tons	Approx Cost
3-phase up to 36 kV	1	3	$90,000
3-phase up to 36 kV	2.5	6	$180,000
3-phase up to 123 kV	5	18	$400,000
3-phase up to 123 kV	10	39	$600,000
3-phase up to 145 kV	16	48	$700,000
3-phase up to 145 kV	20	54	$800,000
3-phase up to 145 kV	25	61	$900,000
3-phase up to 145 kV	40	82	$1,000,000
3-phase up to 145 kV	50	97	$1,100,000
3-phase up to 145 kV	100	118	$1,800,000
3-phase up to 145 kV	300	170	$2,000,000
3-phase up to 145 kV	500	335	$4,000,000
3-phase up to 145 kV	750	410	$7,500,000

7. Components in Transformers

A transformer is made up generally of the following components and materials

- Laminated Electric Steel Core
- Primary & Secondary Copper or Aluminum Windings
- Insulating Materials – Insulating Paper/Board and Mineral Oil
- Tap Changer – Steel, Copper, Insulating Materials, Oil
- Oil conservator - Steel tank & piping
- Breather - Steel, plastic & silica gel
- Cooling tubes - Steel

The cost of these internal raw materials is significant, accounting for around 50 percent of the total cost of a typical Large Power Transformer (LPT).
Manufacturers have estimated that the total cost of raw materials accounted for 57 to 67 percent of the total cost of LPTs sold in the United States between 2008 and 2010. Of the total material cost, about 18 to 27 percent was for copper, 22 to 24 percent was for electrical steel and 5% for paper insulating materials.

8. Transformer failure causes and rates of failure

A Transformer Reliability Survey carried out in 2015 CIGRE reported:

- Winding related failures appeared to be the largest contributor of major failures, irrespective of transformer application or manufacturing period, and due to their impact typically led to a situation where the failed transformer was scrapped.
- GSU transformers had higher contributions of winding and lead exit failures than substation transformers.
- Substation transformers on the other hand had higher contributions of tap changer related failures than GSU transformers.
- Dielectric mode failures were among the most prominent, irrespective of transformer application and voltage class.

Figure's 1 & 2 show the failure locations from a CIGRE Working Group AG.37:1983

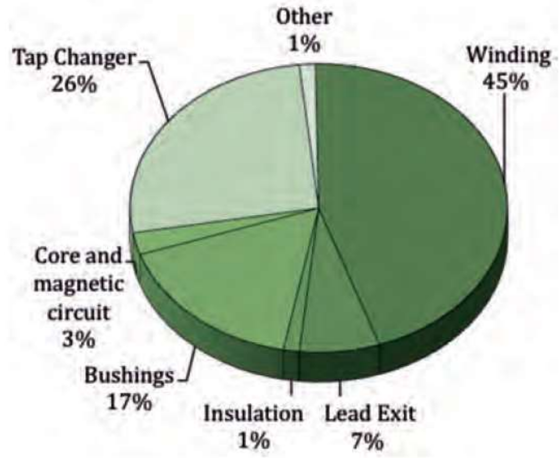


Figure 1: Failure locations of Substation Transformers (>100kV) (based on 364 failures)

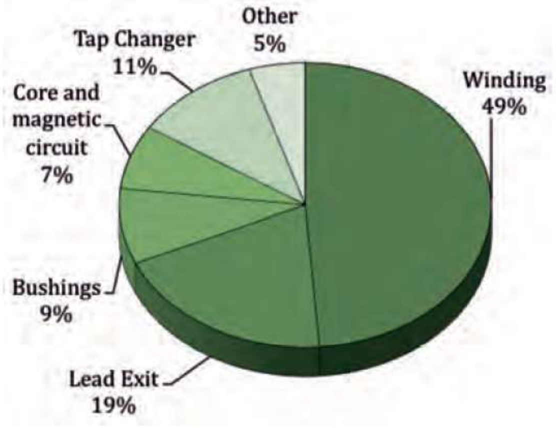


Figure 2: Failure Locations in Generator Step-Up Transformers (>100 kV) (based on 82 failures)

Most of the failures described above generate Hot-Spots within the transformer, causing the precipitation of Hydrogen gas. With no awareness of component problems within the transformer, risk of serious damage even explosion is a possibility.

A transformer reliability survey conducted by CIGRE in 2015, indicated a failure rate of between 0.35% in low voltage units and 2.9% in higher voltage units, with a higher incidence in older units.

Installation of an H2Scan Hydrogen analyser would provide early indication of faults within the transformer providing the opportunity to intervene and avoid further costly damage to the transformer.

Sample LPT Failure Statements:

- ***TD World Cause of Hydrogen Gas In Transformers- March 2014***
  "Hydrogen is produced by partial discharge in the oil, in locations where the electric field stress is high."
- ***Grouper.ieee.org Hydrogen Gas Generation Due to Moderately Overheated Transformer Cores Ramsis Girgis, Fellow, IEEE, and Ed G. teNyenhuis, Member, IEEE***
  "It was found that this gas generation phenomenon was caused by moderately overheated cores with core hot spot temperatures in the 120 – 160 ºC range."
- *"A more recent case of core hydrogen gassing is examined in detail. For this case, calculated gassing rates are compared with actual field and factory measured rates to verify the core gassing phenomena and the developed relationship between core hot spot temperature and core gassing. This core gassing is shown to occur under a certain combination of core excitation, ambient temperature, and loading conditions."*
- *"These factory tests concluded that the hydrogen gassing was related to core over – excitation and not partial discharge."*
- *"Recent events with a 600 MVA transformer indicated the hydrogen gassing phenomena while energized, over a period of approximately 5 months, at no load in a location of hot weather during the summer months with no fans running."*
- *After providing an overview of the discovery of the mechanism of hydrogen gas generation due to elevated core hot spot temperatures, measured H2 generation of a 600 MVA transformer in the field was shown to be in an excellent agreement with the corresponding calculated values. This agreement again confirmed this hydrogen gas generation phenomena, the accuracy of the core hot spot calculation method, and the developed relationship presented in this paper between hydrogen generation rate and core hot spot temperature. Predicted gas generation and accumulation from this transformer with added cooling were calculated using actual load cycle of the transformer and typical average daily ambient temperatures throughout the year in the region the transformer is located. The study demonstrated how that significant accumulation of hydrogen is not common to transformers as it requires a combination of sustained long daily periods of high loading, core over – excitation, and ambient temperatures for many months or even years. Finally, the hydrogen gas accumulation does not pose any risk to the transformer; however, it may mask gassing problems that are dangerous. Industry standards are being revised to recognize this phenomenon and a 130°C limit for core hot spot temperature is recommended."*

9. Consequence of transformer failure

In the event of major component failure or explosion the replacement of the transformer could impact service provision due to delays in replacement, dependent on the scale of the failure.
Serious costs could be incurred with significant carbon emissions in manufacture, transport, and installation of replacement.
In the event of a break in containment of oil chamber, leakage of oil would add an environmental impact and clean up requirement.

With a Global Installed base around 12 million transformers across the GSU Transformer (13%), Transmission Sub Transformers (18%), LP & MP Sub Transformers (55%), Industrial Sub Transformers (5%) and Industrial Transformers (8%) ranges (Newton Evan DGA & M&D Market assessment 2015 update.)
On a 40-year transformer life span around 300,000 new transformers will be manufactured in a single year.
Hartford Steam Boiler & Inspection & Insurance Co. International Association of Insurers 36th Annual Conference – Stockholm 2003
Transformer failures in preceding 5 years 1997 to 2001 transformers 25MVA and above amounted to a total of 94, The largest number (38) were in the Utility substation sector.

Table 1 – Number and Amounts of Losses by Year

Table 1	Total # of Losses	Total Loss	Total Property Damage	Total Business Interruption
1997	19	$ 40,779,507	$ 25,036,673	$ 15,742,834
1998	25	$ 24,932,235	$ 24,897,114	$ 35,121
1999	15	$ 37,391,591	$ 36,994,202	$ 397,389
2000	20	$ 150,181,779	$ 56,858,084	$ 93,323,695
2001	15	$ 33,343,700	$ 19,453,016	$ 13,890,684
Grand Total	94	$ 286,628,811	$ 163,239,089	$ 123,389,722

** Total losses in 2000 includes one claim with a business interruption portion of over $86 million US*

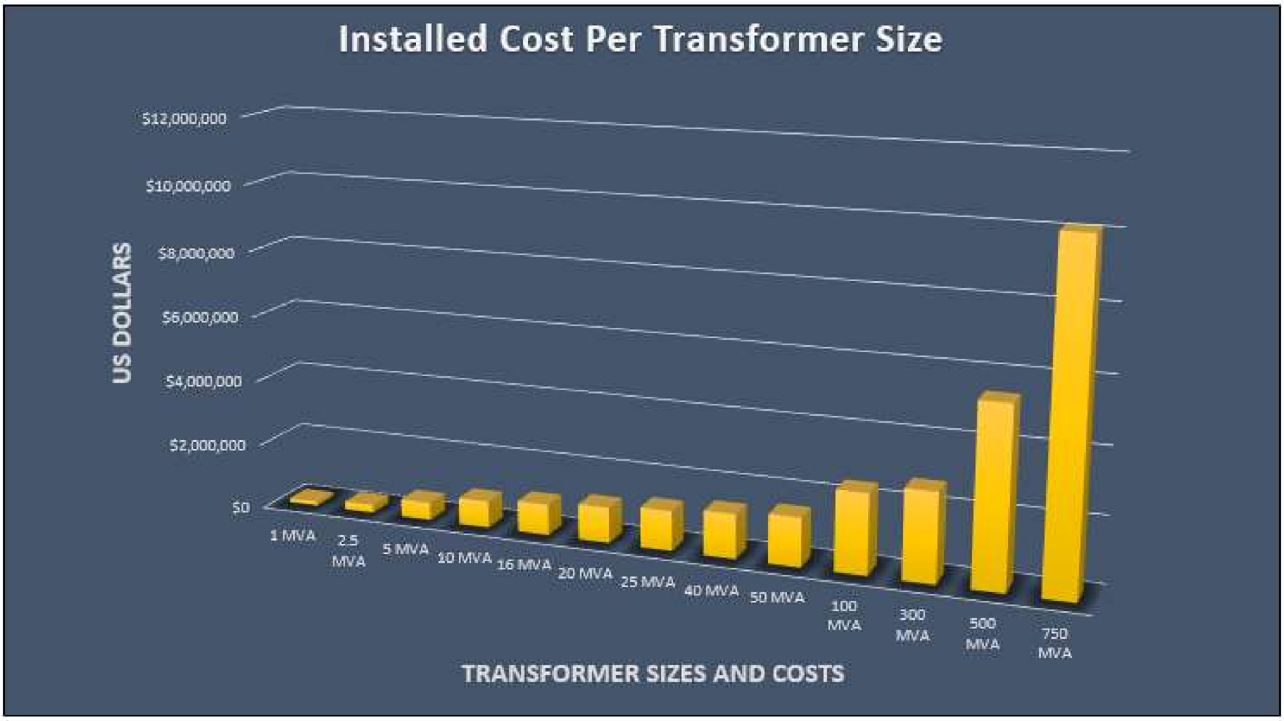
A 0.35-2.9% failure and replacement rate on a 12 Million installed base would require replacement of 42,000-348,000 units per year and have significant cost implications. Based on emissions of all transformer sizes, there is a total potential emissions of 18- 400 Million tons of carbon in a single year.

10. Cost of replacement transformers

The cost of replacing a failed transformer is not limited to the cost of the transformer and its transport, there is the planning an engineering costs associated with removal of an old unit being replaced by a unit of different size and weight. The removal of the existing transformer, any environmental clean-up required dependent on the type and extent of failure, plus the disposal of the failed transformer.

Financial Cost of Transformer Replacement

Transformer Size & Rating	Transformer Weight Tons	New Replacement Cost	Planning & Engineering Costs Estimated at 10% of cost	Transport to and lifting at site at 5% of cost	Cost of Installation estimated at 10% of cost	Transport to and lifting at site of Failed Unit at 5% of cost	Breakdown & disposal cost of failed transformer, estimated 5% of cost	Estimated Total Cost of installed transformer
3-phase up to 36 kV 1 MVA	3	$90,000	$9,000	$4,500	$9,000	$4,500	$4,500	$121,500
3-phase up to 36 kV 2.5 MVA	6	$180,000	$18,000	$9,000	$18,000	$9,000	$9,000	$243,000
3-phase up to 123 kV 5 MVA	18	$400,000	$40,000	$20,000	$40,000	$20,000	$20,000	$540,000
3-phase up to 123 kV 10 MVA	39	$600,000	$60,000	$30,000	$60,000	$30,000	$30,000	$810,000
3-phase up to 145 Kv 16 MVA	48	$700,000	$70,000	$35,000	$70,000	$35,000	$35,000	$945,000
3-phase up to 145 kV 20 MVA	54	$800,000	$80,000	$40,000	$80,000	$40,000	$40,000	$1,080,000
3-phase up to 145 Kv 25 MVA	61	$900,000	$90,000	$45,000	$90,000	$45,000	$45,000	$1,215,000
3-phase up to 145 kV 40 MVA	82	$1,000,000	$100,000	$50,000	$100,000	$50,000	$50,000	$1,350,000
3-phase up to 145 kV 50 MVA	97	$1,100,000	$110,000	$55,000	$110,000	$55,000	$55,000	$1,485,000
3-phase up to 145 kV 100 MVA	118	$1,800,000	$180,000	$90,000	$180,000	$90,000	$90,000	$2,430,000
3-phase up to 145 kV 300 MVA	170	$2,000,000	$200,000	$100,000	$200,000	$100,000	$100,000	$2,700,000
3-phase up to 145 kV 500 MVA	335	$4,000,000	$400,000	$200,000	$400,000	$200,000	$200,000	$5,400,000
3-phase up to 145 kV 750 MVA	410	$7,500,000	$750,000	$375,000	$750,000	$375,000	$375,000	$10,125,000



11. Methodology in the calculation of Carbon emissions

The methodology for calculation of carbon emissions for transformer manufacture, transport, installation and disposal are based on the Greenhouse Gas Protocol and global databases to determine:

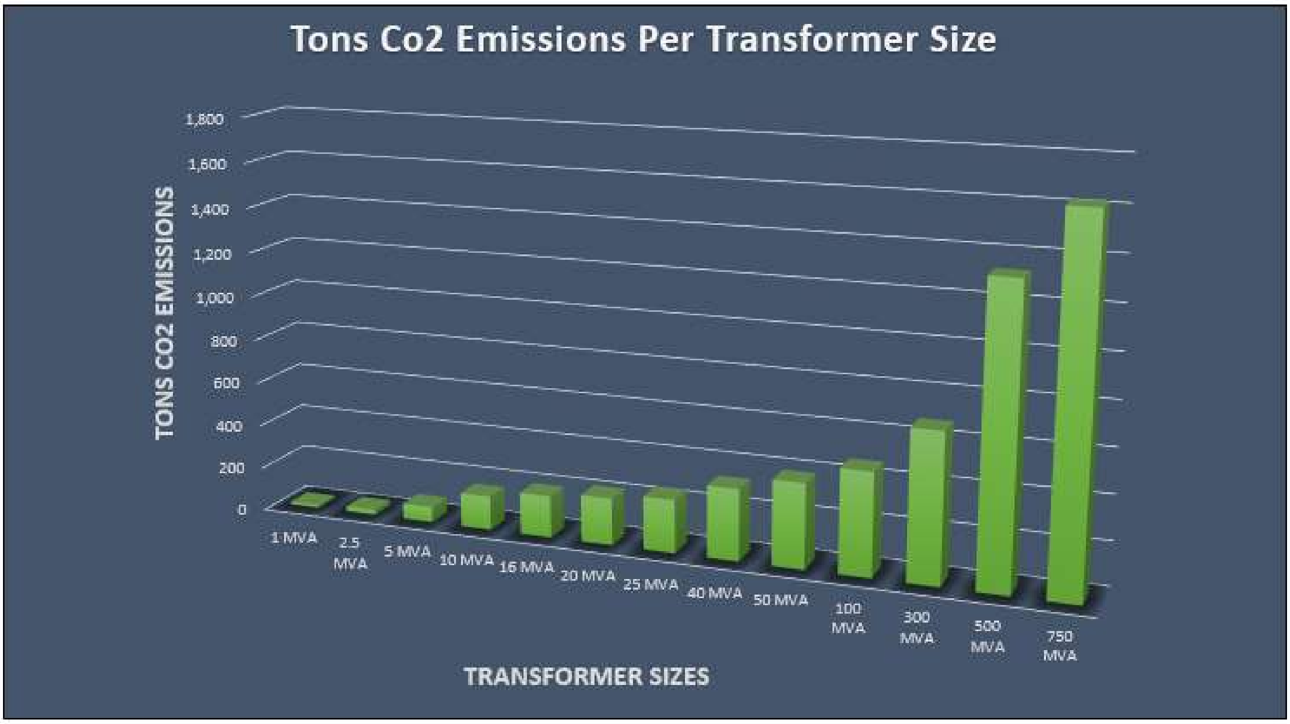
- Embodied carbon on raw-material manufacture
- Carbon emissions associated with manufacture and assembly of transformers and components.
- Heavy load transport of transformers to a generic 500-mile distant site with a return journey with the failed transformer
- Disposal of failed transformer and its components in a Closed Loop disposal (materials recycled as same product).

12. Associated Carbon Emissions

Carbon Emissions from Transformer Replacement

Transformer Voltage Rating	MVA Rating	Transformer Weight Short Tons	Transformer Weight in kg @907.2 /Ton	Emissions in Manufacture of Raw Materials Primary Electrical Steel Plate (23% of wt) 3.29kg CO2/kg Primary Copper for Windings (23% of wt) 3.83kg CO2/kg Fabrication Steel Etc (49% of wt) 2.0 kg CO2 /kg Paper & Board Insulation (5% of wt) 2.25 kg CO2 /kg				Transformer Manufacturing Emissions estimated @ 1kg CO2/kg	Transport Emissions 1000 miles. 201gCO2/ Ton Mile. kg Ton Mile	Installation Emissions 300g CO2/Ton	Emissions in Closed Loop Recycling of the failed transformer and it components 1.009 kgCO2/Ton	Total Carbon Emissions in a new Transformer Installation kg CO2	*Total Carbon Emissions in a new Transformer Installation in Tons CO2
				Electrical Steel	Copper	Fabrication Steel etc	Paper Insulation						
3-phase up to 36 kV	1	3	2,722	2,059	2,397	2,667	306	2,722	603	1	3	10,759	12
3-phase up to 36 kV	2.5	6	5,443	4,119	4,795	5,334	612	5,443	1206	2	6	21,518	24
3-phase up to 123 kV	5	18	16,330	12,357	14,385	16,003	1,837	16,330	3618	5	18	64,553	71
3-phase up to 123 kV	10	39	35,381	26,773	31,167	34,673	3,980	35,381	7839	12	39	139,864	154
3-phase up to 145 kV	16	48	43,546	32,951	38,359	42,675	4,899	43,546	9648	14	48	172,140	190
3-phase up to 145 kV	20	54	48,989	37,070	43,154	48,009	5,511	48,989	10854	16	54	193,658	213
3-phase up to 145 kV	25	61	55,339	41,875	48,748	54,232	6,226	55,339	12261	18	62	218,762	241
3-phase up to 145 kV	40	82	74,390	56,291	65,531	72,903	8,369	74,390	16482	25	83	294,073	324
3-phase up to 145 kV	50	97	87,998	66,588	77,518	86,238	9,900	87,998	19497	29	98	347,867	383
3-phase up to 145 kV	100	118	107,050	81,004	94,300	104,909	12,043	107,050	23718	35	119	423,178	466
3-phase up to 145 kV	300	170	154,224	116,701	135,856	151,140	17,350	154,224	34170	51	172	609,663	672
3-phase up to 145 kV	500	335	303,912	229,970	267,716	297,834	34,190	303,912	67335	101	338	1,201,396	1,324
3-phase up to 145 kV	750	410	371,952	281,456	327,653	364,513	41,845	371,952	82410	123	414	1,470,365	1,621

***Total Estimated Carbon Emissions associated with new transformer exclude manpower mobilization.**



13. Conclusion

It is clear transformers are a significant component in Electrical Power Grids. They are heavy and powerful pieces of equipment, are expensive to produce, and usually on long delivery lead times. Any opportunity to reduce the failure of these critical units should be a prime consideration to reduce the massive financial costs of replacement, property damage, business interruption and significantly reduce carbon emissions that are damaging our planet.

For a low cost, the H2scan Hydrogen Sensor can significantly aid a Power Companies' preventative maintenance strategies and help improve safety, profitability, service and above all our fragile planet!

14. Contact Details

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