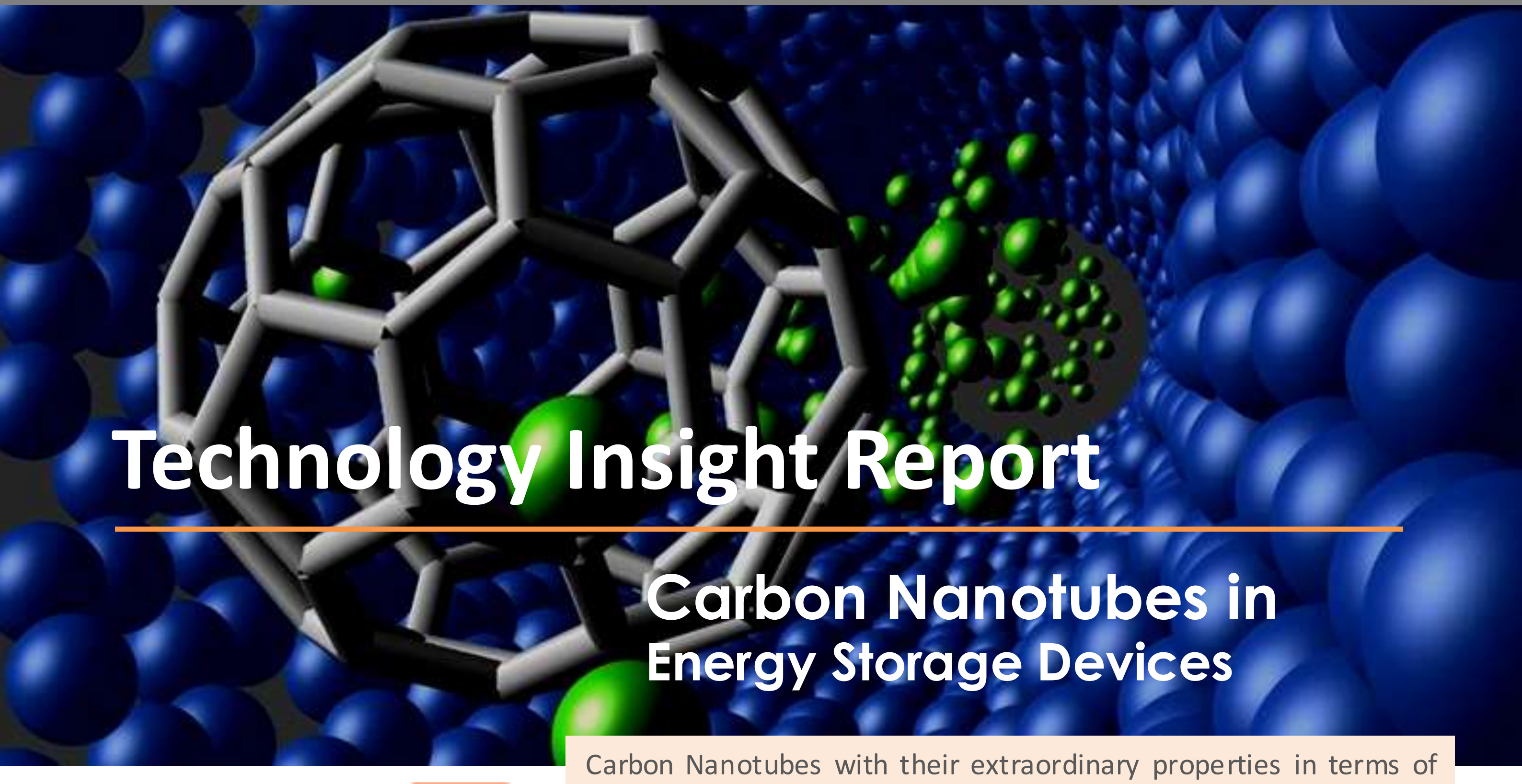

Technology Insight Report

Carbon Nanotubes in Energy Storage Devices

Patent iNSIGHT Pro
Transform Patents to Intelligence

Carbon Nanotubes with their extraordinary properties in terms of strength, thermal and electrical properties are poised to have a big impact on the future of material sciences, electronics and nanotechnology. Owing to their specialized structures and minute diameter, they can be utilized in the creation of ultra-thin energy storage devices which in today's world where electronics is getting smaller could redefine the electronics market and replace capacitors and batteries they way we see them now. Research and development around carbon nanotubes is moving ahead yielding new forms, new applications and new material based on this unique structure and we take a look into this breakthrough in science and the innovation that surrounds it as it promises to be a large part or small devices of the future.

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Overview

Introduction to Carbon Nanotubes

Carbon nanotubes (CNTs; also known as buckytubes) are allotropes of carbon with a cylindrical nanostructure. Nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1, which is significantly larger than any other material. These cylindrical carbon molecules have novel properties that make them potentially useful in many applications in nanotechnology, electronics, optics and other fields of materials science, as well as potential uses in architectural fields. They exhibit extraordinary strength and unique electrical properties, and are efficient thermal conductors.

Nanotubes are members of the fullerene structural family, which also includes the spherical buckyballs. The ends of a nanotube might be capped with a hemisphere of the buckyball structure. Their name is derived from their size, since the diameter of a nanotube is on the order of a few nanometers (approximately 1/50,000th of the width of a human hair), while they can be up to 18 centimeters in length (as of 2010). Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs)

Source: http://en.wikipedia.org/wiki/Carbon_nanotube

The Market for Carbon Nanotubes

While the use of carbon nanotubes in energy storage devices is a newly emerging technology, the current global market for nanotubes according to a report by Global Industry Analysts Inc is estimated in excess of $ 1.9 billion.

By 2012 as more of the applications enter into the markets, this figure is estimated to go up to $5 billion. As the production prices fall and the demand for carbon nanotubes and the demand increases across the different application areas, we can expect to see this climb even further. The current growth rate for Carbon nanotubes was previously pegged at 40% annually according to another report on Chemical Sciences but many believe the reduction of production costs and how soon electronic device companies will adapt to the use of Carbon nanotubes will be major determining factors in future success of this material.

The report by Global Industry Analysts Inc suggests that the global market for Carbon nanotubes can be expected to skyrocket over the next few years despite a slower start since its discovery.

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Special Properties of Carbon Nanotubes

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Some of the unique properties of carbon nanotubes include:

Strength

Carbon nanotubes are the strongest and stiffest materials yet discovered in terms of tensile strength and elastic modulus respectively. This strength results from the covalent sp^2 bonds formed between the individual carbon atoms. In 2000, a multi-walled carbon nanotube was tested to have a tensile strength of 63 gigapascals (GPa). This translates into the ability to endure tension of a weight equivalent to 6422 kg on a cable with cross-section of 1 mm2.

Hardness

Diamond is considered to be the hardest material, and it is well known that graphite transforms into diamond under conditions of high temperature and high pressure. One study succeeded in the synthesis of a super-hard material by compressing SWNTs to above 24 GPa at room temperature. The hardness of this material was measured with a nanoindenter as 62–152 GPa. The hardness of reference diamond and boron nitride samples was 150 and 62 GPa, respectively.

Kinetic

Multi-walled nanotubes, multiple concentric nanotubes precisely nested within one another, exhibit a striking telescoping property whereby an inner nanotube core may slide, almost without friction, within its outer nanotube shell thus creating an atomically perfect linear or rotational bearing. This is one of the first true examples of molecular nanotechnology, the precise positioning of atoms to create useful machines. Already this property has been utilized to create the world's smallest rotational motor.

Electrical

Because of the symmetry and unique electronic structure of graphene, the structure of a nanotube strongly affects its electrical properties. They function as semiconductors. Multiwalled carbon nanotubes with interconnected inner shells show superconductivity with a relatively high transition temperature Tc = 12 K. In contrast, the Tc value is an order of magnitude lower for ropes of single-walled carbon nanotubes or for MWNTs with usual, non-interconnected shells.

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Thermal

All nanotubes are expected to be very good thermal conductors along the tube, exhibiting a property known as "ballistic conduction", but good insulators laterally to the tube axis. Measurements show that a SWNT has a room-temperature thermal conductivity along its axis of about 3500 $W \cdot m^{-1} \cdot K^{-1}$; compare this to copper, a metal well-known for its good thermal conductivity, which transmits 385 $W \cdot m^{-1} \cdot K^{-1}$.

Source: http://en.wikipedia.org/wiki/Carbon_nanotube

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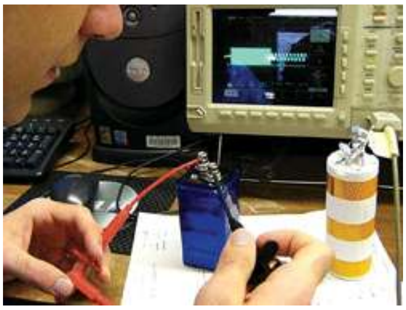
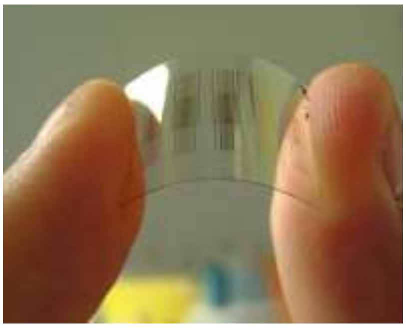
Carbon Nanotubes in Energy Storage

Inducing purposeful defects in the structures of carbon nanotubes has given them the ability to perform as super-capacitors which has huge implications to the future of energy storage, batteries and electronic devices that rely on stored energy. Research in this area has already resulted in the development of energy storage devices which are smaller, higher storage capacity and can be recharged far quicker than existing batteries which can be a leap in terms of nanotechnology.

Student research groups are reported to have developed paper thin batteries made up of cellulose embedded with carbon nanotubes. The thin paper-like structure which is also flexible could allow these to be stacked in larger amounts for greater energy requirements and can well redefine the way we see batteries and energy storage devices in our everyday devices. With considerable research going on around the use of carbon nanotubes to come up with solutions for energy storage, it can well be the innovation that shapes the advances in future material science and nanotechnology.

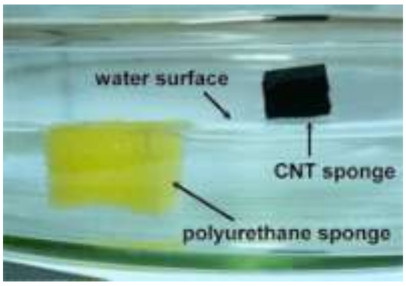


Energy storage devices research with Carbon nanotubes



Nanosensors with Carbon nanotubes visible

The paper battery



Carbon nanotube sponge

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Categories defined for Use of Carbon Nanotubes in Energy Storage Devices

We categorized carbon nanotubes patents along the following lines:

- Types of carbon nanotubes
- Properties of carbon nanotubes
- Use across different energy storage devices

Categorization: Types of carbon nanotubes

- Single-wall Nanotubes (SWNT)
- Multi-wall Nanotubes (MWNT)
- Fullerene Nanotubes
- Double-wall Nanotubes (DWNT)
- Cup stacked carbon nanotubes (CSCNTs)

Categorization: Properties of carbon nanotubes

1. Chemical-Biochemical Properties
   - Capillarity
   - High Specific Surface Area
2. Conductive Properties
   - Anisotropic
   - Electrical conductivity
   - Field emission
   - Heat conductivity
   - High current density
3. Defects
   - Schottky defect
4. Electrical Properties
5. Magnetic Properties
   - Diamagnetic
   - Ferromagnetic
   - Magnetic field
   - Paramagnetic
6. Mechanical Properties
   - Density
   - Flexible
   - Tensile and Compressive
   - Strength
   - Young Modulus
7. Optical Properties
   - Absorption
   - Photoluminescence
   - Raman spectroscopy
8. Physical Properties
   - Ability to be manipulated
   - Electronic structure
   - Hardness
   - Impervious to Environmental Factors
   - One- Dimensional Transport
   - Strength
   - Toxicity
9. Thermal Property
   - Ballistic Conduction

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Categorization: Energy Storage Devices

1. Chemical
   - Biofuels
   - Hydrogen
   - Hydrogen peroxide
   - Liquid nitrogen
   - Oxyhydrogen

2. Electrical
   - Capacitor
   - Super-capacitor
   - Superconducting Magnetic Energy Storage (SMES)

3. Electrochemical
   - Batteries
   - Flow Batteries
   - Fuel cells

4. Mechanical
   - Compressed Air Energy Storage (CAES)
   - Flywheel Energy Storage
   - Hydraulic Accumulator
   - Hydroelectric energy storage
   - Spring

5. Thermal
   - Cryogenic Liquid Air Or Nitrogen
   - Eutectic System
   - Heat storage
   - Molten salt
   - Solar cell
   - Steam accumulator

For this analysis, we created patent buckets for the above mentioned categories using Patent iNSIGHT Pro's User Defined Categories. Various search strings were prepared for each category. The advanced searching interface was used to search across the Full-Text and/or TAC of each record. The results were pushed into the corresponding bucket.

Please refer Appendix B for more details on the search strings used for each category level.

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Carbon Nanotubes – Insights from Patents

Insight Overview

While we can get some perspective of Carbon nanotubes' technology as well as it's applications with energy storage devices from the overviews in previous paragraphs of this report, the patent filings around this technology help cover some more angles in this area.

IP activity and patent data are great indicators of exactly what is happening in this space and could help uncover several insights while answering questions that manufacturers, technology enthusiasts, inventors, scientists, investors and others would seek answers to.

- When did IP activity around this technology start picking up and is it still showing a strong increase?
- Where are most of these filings coming from?
- Who are the top assignees of patents in this field?
- Who are the key innovators?

The Search Strategy

The first step is to create and define a patent set that will serve as the basis of our analysis. Innovations around "Carbon Nanotubes" have been made primarily in the areas of "Types", "Properties" and "Energy Storage Devices".

Using the commercial patent database, PatBase as our data source, we used the following search queries to create our patent set:
((FT=(CNT* or SWNT* or DWNT* or TWNT* or MWNT* or bucky-tube* or buckytube* or ((carbon or "Single Wall*" or "Double Wall*" or "Thin wall*" or "multi-wall*" or "Single-Wall*" or "Double-Wall*" or "Thin-wall*" or "multi-wall*") w/5 (nanotube* or nano-tube*)))) and (UC=(429)))

The query was directed to search through the full text (FT) and US Classification '429' and a record set of 5326 families was generated.

Class Description:

429 - CHEMISTRY: ELECTRICAL CURRENT PRODUCING APPARATUS, PRODUCT, AND PROCESS

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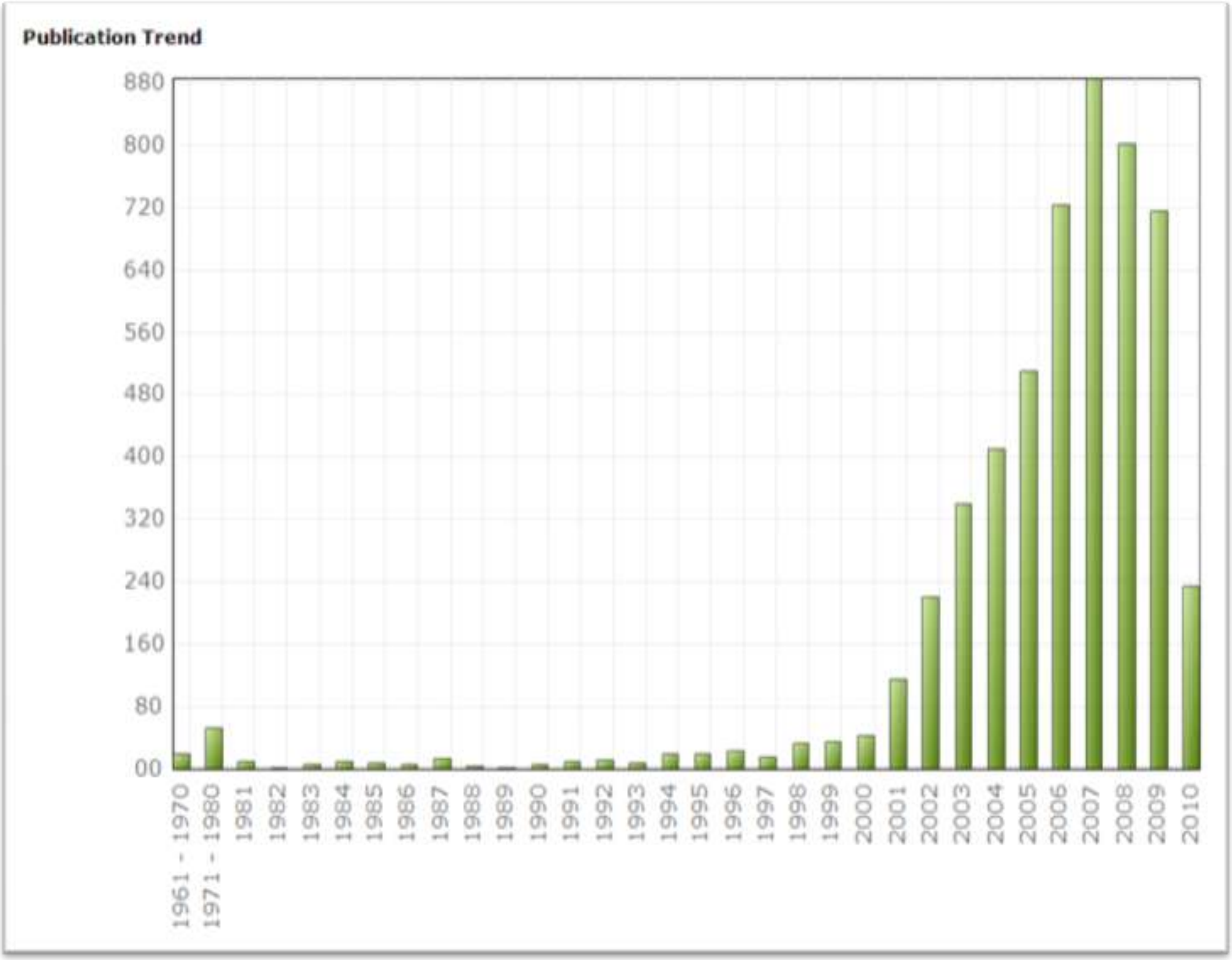
Publication Trend

What has been the IP publication trend for Carbon Nanotubes?



The patent publication trend in the form of a bar graph shows activity from as early as the 1960's and 1970's, although the number of filings remained relatively low all the way up till the year 2000. From 2001 which saw a jump to over 100 patents published, there were huge leaps in the patents published with every year till 2007 which saw more than 880 patents. There has been a slight dip since then but overall, the patents published around carbon nanotubes in energy storage device has remained high and looks to be going strong.

How we did it?

Once the patents were populated in Patent iNSIGHT Pro, the publication trend chart was generated on a single click using the dashboard tool.

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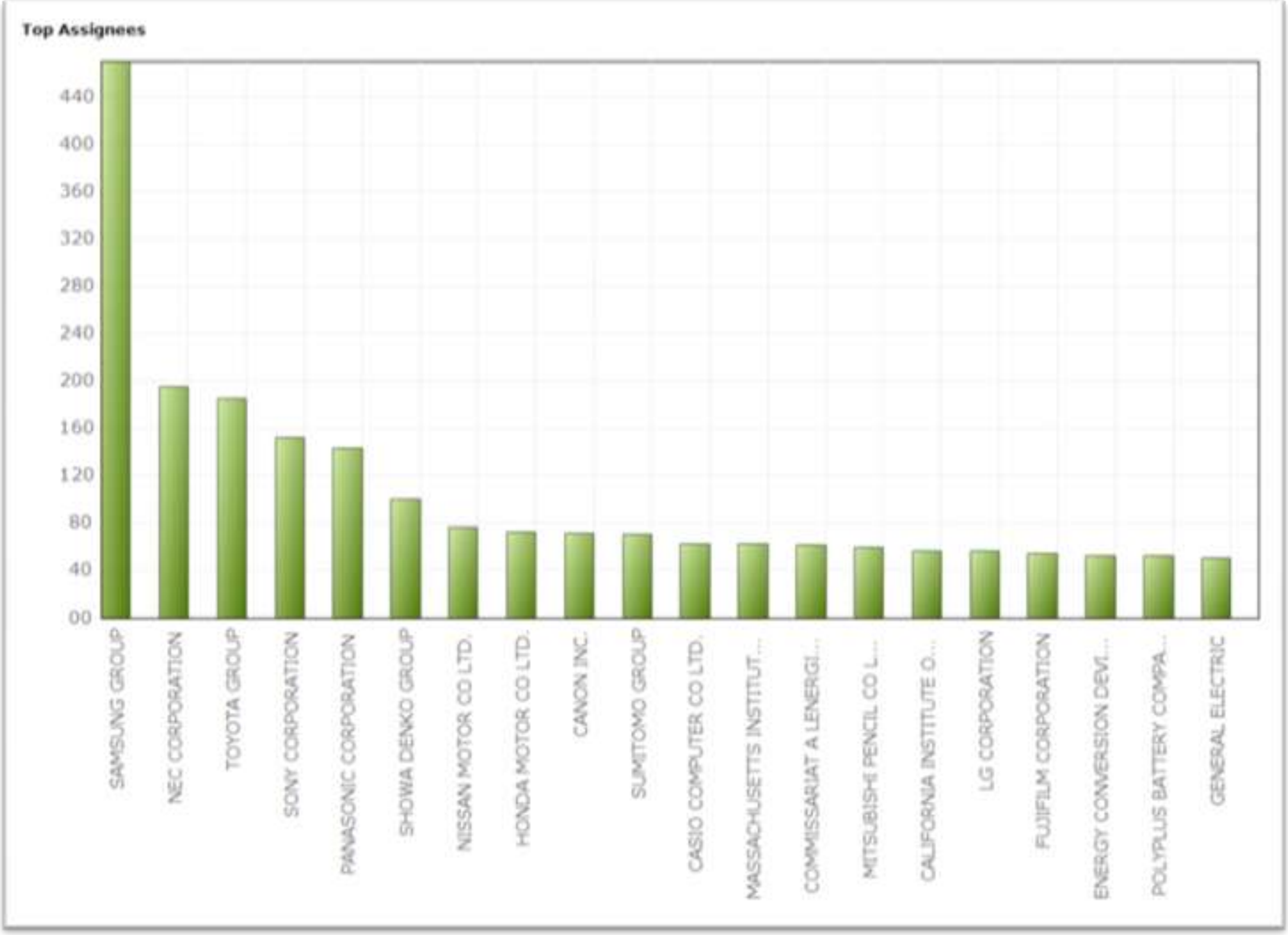
Top Assignees

Who have been the top assignees or the key players for carbon nanotubes?



The Top Assignees are:

1. Samsung Group
2. NEC Corporation
3. Toyota Group
4. Sony Corporation
5. Panasonic Corporation
6. Showa Denko Group
7. Nissan Motor Co. Ltd.
8. Honda Motor Co Ltd.
9. Canon Inc
10. Sumitomo Group
11. Casio Computer Ltd.
12. Massachusetts Institute Of Technology
13. Commissariat A Lenergie Atomique
14. Mitsubishi Pencil Co Ltd.
15. California Institute of Technology
16. LG Corporation

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17. Fujifilm Corporation
18. Energy Conversion Devices
19. Polyplus Battery Company
20. General Electric

How we did it?

Once the patents were populated in Patent iNSIGHT Pro, the assignee clean-up tools were used to normalize the names. Different cleanup tools were leveraged:

- To locate assignees for unassigned records
- To clean up records having multiple assignees
- To locate the correct assignee names for US records using the US assignments database
- To merge assignees that resulted from a merger or acquisition or name change.

Please refer Appendix A for more details on Assignee merging.

Once the Assignee names were cleaned up, the dashboard tool within Patent iNSIGHT Pro was used to find the top 20 assignees within the given patent set. A visual graph was created based on the results of the top assignees with the number of patents alongside each one.

Also, see full Assignee count table in following excel sheet:

List of top assignees
http://www.patentinsightpro.com/techreports/0710/Top%20Assignees.xls

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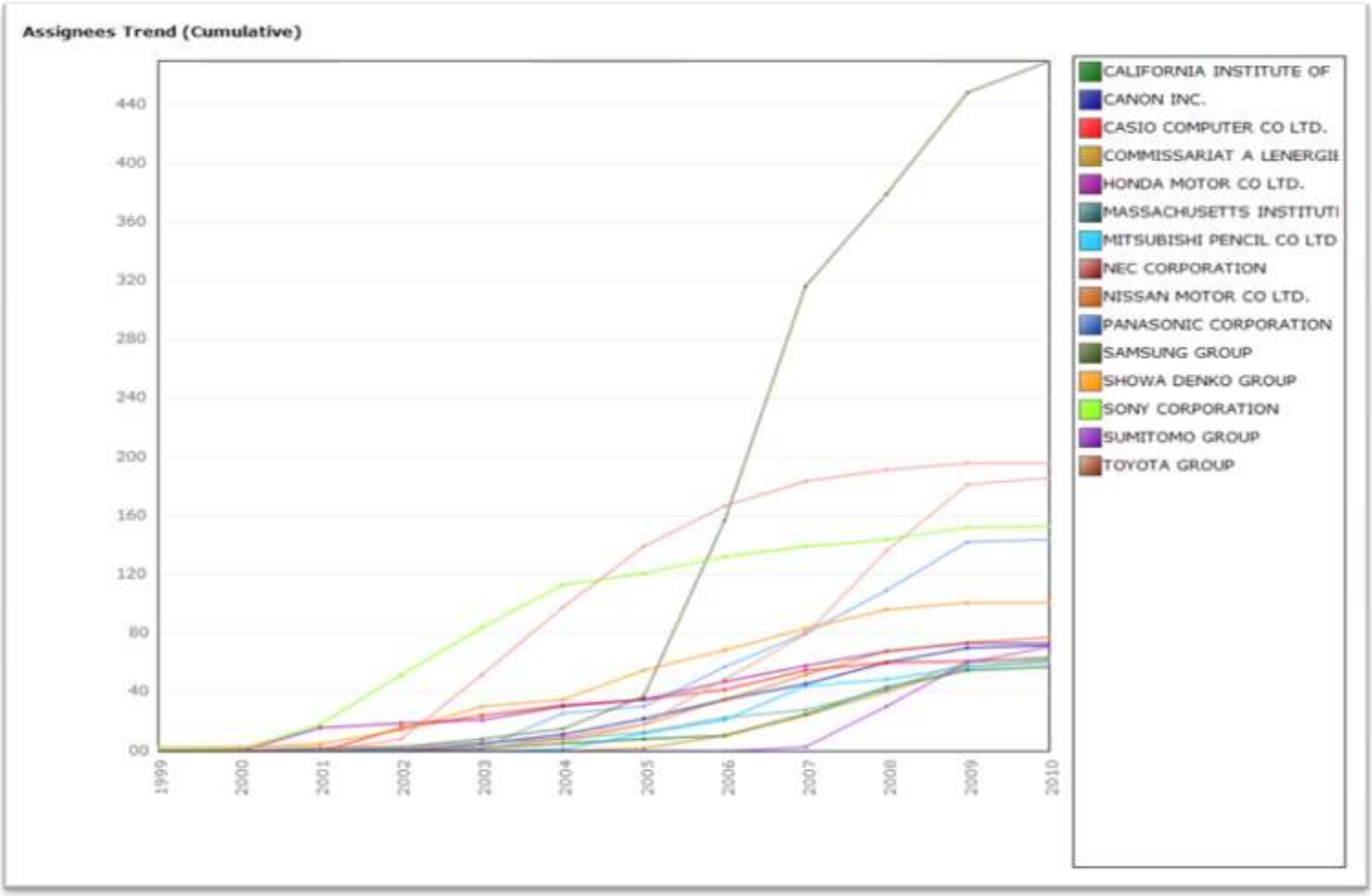
Top Assignee Trends



Above is the assignee trend for patents assigned to the top assignees identified within the patent set for carbon nanotubes shown with respect to time. The olive green trend line associated with Samsung Group shows an impressive spike from 2005 onwards where there seems to have been a frenzy of research around carbon nanotubes over a shorter period of time which has taken Samsung Group right to the top of the assignees list with the highest number of patents within this space. Interestingly, MIT and California Institute of Technology who rank in the top assignees also seem to have been pursuing carbon nanotube research for a significant number of years.

How we did it?

Using the Report Dashboard in Patent iNSIGHT Pro, the graph showing the cumulative filings of top 15 assignees with respect to time was created. The output was created in the form of a line graph to get a visual insight which could display comparisons across the assignees.

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Assignee - Key Statistics

Here we summarize key parameters of Top 15 Assignees such as filing trend, Avg. number of Forward citations per record, Top inventors, Top Co-Assignees and Coverage of underlying patent families.

Assignee	Total No. of Records	Average No.of Fwd Cites per Patents	Filing Trend (Absolute)	Filing Year Range	Key Inventor (Top 5)	Co-Assignees	Coverage (Includes families)						
							US	EP	WO	JP	DE	GB	CA
SAMSUNG GROUP	470 (8.8%)	0.24		1999-2009	KWAK CHAN(70) KWEON HO JIN(67) LEE SI HYUN(49) KIM HEE TAK(40) PAK CHAN HO(37)	PANASONIC CORPORATION(6) DALIAN INSTITUTE OF CHEMICAL PHYSICS(3) KIM HA SUCK(3) UNIVERSITY OF CALIFORNIA(2) CHANG HYUK(1)	109	36	3	61	10	0	0
NEC CORPORATION	196 (3.7%)	0.49		2000-2008	YOSHITAKE TSUTOMU(86) KUBO YOSHIMI(76) KIMURA HIDEKAZU(74) MANAKO TAKASHI(57) KUROSHIMA SADANORI(56)	KUBO YOSHIMI(19) YOSHITAKE TSUTOMU(19) KIMURA HIDEKAZU(17) MANAKO TAKASHI(17) KUROSHIMA SADANORI(10)	38	6	27	48	1	0	4
TOYOTA GROUP	186 (3.5%)	0.37		1998-2009	KANO HIROYUKI(20) SUGIYAMA TORU(20) NAKAMURA YOSHIYUKI(19) HIRAMATSU MINEO(18) HORI MASARU(18)	HIRAMATSU MINEO(15) HORI MASARU(15) TSUCHIYA CO LTD.(8) CATALER CORPORATION(7) NAKAMURA YOSHIYUKI(7)	40	23	30	44	9	0	17
SONY CORPORATION	153 (2.9%)	0.88		1997-2009	YAMAURA KIYOSHI(30) HINOKUMA KOICHIRO(30) IMAZATO MINEHISA(26) ATA MASAFUMI(20) TANAKA KOICHI(17)	KAJIURA HISASHI(8) SHIRAISHI MASASHI(7) NEGISHI EISUKE(6) ATA MASAFUMI(5) SHIRAI KATSUYA(4)	66	14	26	19	2	0	8
PANASONIC CORPORATION	144 (2.7%)	0.39		2002-2009	MATSUDA HIROAKI(18) YOSHIZAWA HIROSHI(14) ISHIDA SUMIHITO(13) SATO TOSHITADA(12) YAMAMOTO TERUAKI(11)	SAMSUNG GROUP(6) YOSHIZAWA HIROSHI(4) ISHIDA SUMIHITO(3) MATSUDA HIROAKI(3) ASARI TAKUMA(2)	41	9	13	36	2	0	0
SHOWA DENKO GROUP	101 (1.9%)	1.03		2000-2009	IINO TADASHI(32) NISHIMURA KUNIO(19) IZUMI ZENICHIRO(19) NOGUCHI MASAYUKI(19) KOBAYASHI TOMOAKI(18)	HONDA MOTOR CO LTD.(8) IINO TADASHI(7) IZUMI ZENICHIRO(4) KOBAYASHI TOMOAKI(3) NOGUCHI MASAYUKI(3)	32	13	16	24	2	0	2
NISSAN MOTOR CO LTD.	77 (1.4%)	0.94		2002-2008	SHIMAMURA OSAMU(11) HOSAKA KENJI(11) HORIE HIDEAKI(11) YAMAMOTO SHINJI(9) SAITO TAKAMITSU(9)	KAO CORPORATION(5) KYUSHU UNIVERSITY(4) SAITO TAKAMITSU(3) HORIE HIDEAKI(2) HOSAKA KENJI(2)	23	16	12	20	3	0	5
HONDA MOTOR CO LTD.	73 (1.4%)	0.79		2001-2009	KUBOTA TADAHIRO(27) KURIYAMA NARIAKI(27) SASAHARA JUN(27) SAITO YUJI(18) LEE SANG JOON JOHN(18)	STANFORD UNIVERSITY(37) SHOWA DENKO GROUP(8) KUBOTA TADAHIRO(5) KURIYAMA NARIAKI(5) SASAHARA JUN(5)	37	13	13	22	4	0	10
CANON INC.	72 (1.4%)	0.63		2002-2010	KOBAYASHI MOTOKAZU(21) KAWAKAMI SOICHIRO(14) ERITATE SHINJI(11) ASAO MASAYA(10)	KOBAYASHI MOTOKAZU(4) ABE KEIKO(2) EGUCHI KEN(2) ERITATE SHINJI(2) KAWAKAMI SOICHIRO(2)	32	4	13	22	0	0	1
SUMITOMO GROUP	71 (1.3%)	0.07		2007-2009	SAITO SHIN(47) KURODA RYUMA(40) KURITA HIROYUKI(35) SHINODA HIROSHI(25) MASUI KENTARO(17)	SAITO SHIN(7) KURODA RYUMA(6) NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY(6)	9	9	9	12	0	0	4
CASIO COMPUTER CO LTD.	63 (1.2%)	0.79		2001-2007	SHIOYA MASAHARU(29) KABASAWA YASUNARI(17) KAMITANI TOSHIMI(16) AKAO HIDETOSHI(10) SUDA YOSHIHISA(9)	MITSUBISHI PENCIL CO LTD.(18) KABASAWA YASUNARI(4) KAMITANI TOSHIMI(4) NISHIMURA KOUJI(2) OSADA TAKAHIRO(2)	10	4	0	14	2	0	6
MASSACHUSETTS INSTITUTE OF TECHNOLOGY	63 (1.2%)	0.33		2001-2009	CHIANG YET MING(33) CHIN TIMOTHY E(13) HELLWEG BENJAMIN(12) BELCHER ANGELA M(11) CIMA MICHAEL J(9)	CHIANG YET MING(7) CHIN TIMOTHY E(6) A123 SYSTEMS INC.(5) UNIVERSITY OF TEXAS(5) BELCHER ANGELA(2)	19	4	9	6	1	0	4
COMMISSARIAT A LENERGIE ATOMIQUE	62 (1.2%)	0.15		2003-2008	LAURENT JEAN YVES(23) GAILLARD FREDERIC(22) SALOT RAPHAEL(13) PLISSONNIER MARC(11) LAMBERT KARINE(9)	CENTRE NAT RECH SCIENT(3) INSTITUT POLYTECHNIQUE DE GRENOBLE(3) LAURENT JEAN YVES(2) ABANADES STEPHANE(1) ARROYO JEAN(1)	11	10	7	9	4	0	0
MITSUBISHI PENCIL CO LTD.	60 (1.1%)	0.30		2002-2009	SUDA YOSHIHISA(41) KAMITANI TOSHIMI(33) OSADA TAKAHIRO(32) YAMADA KUNITAKA(28) KABASAWA YASUNARI(22)	CASIO COMPUTER CO LTD.(18) KAMITANI TOSHIMI(7) SUDA YOSHIHISA(6) KABASAWA YASUNARI(5) OSADA TAKAHIRO(5)	16	9	6	14	1	0	1
CALIFORNIA INSTITUTE OF TECHNOLOGY	57 (1.1%)	0.46		2002-2009	YAZAMI RACHID(41) HAMWI ANDRE(18) CHISHOLM CALUM(7) HAILE SOSSINA M(7) SHI QINGFANG(7)	CENTRE NAT RECH SCIENT(19) YAZAMI RACHID(10) UNIVERSITE BLAISE PASCAL(9) CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE (C.N.R.S.)(8)	18	9	13	7	0	0	3

How we did it?

In order to compress all the information into a single report, we used the new 360° series of reports available in the software. From the Assignee 360° report options, we selected the different pieces of information we wanted to include in the singular display and then ran the report. The generated report was then exported to Excel using the option provided for the same.

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Inventors – Key Statistics

Here we summarize key parameters of Top 15 Inventors such as filing trend, Avg. number of Forward citations per record, Key Associated Companies and Top 5 Co-Inventors.

Inventor	Total No. of Records	Average No. of Fwd Cites per Patents	Filing Trend (Absolute)	Filing Year Range	Key Assignees (Top 5)	Co-Inventors
YOSHITAKE TSUTOMU	88 (1.7%)	0.523		2002-2005	NEC CORPORATION(86) KUBO YOSHIMI(19) YOSHITAKE TSUTOMU(19) MANAKO TAKASHI(15) KIMURA HIDEKAZU(15)	KUBO YOSHIMI(76) KIMURA HIDEKAZU(69) KUROSHIMA SADANORI(56) MANAKO TAKASHI(52) SHIMAKAWA YUICHI(45)
KUBO YOSHIMI	78 (1.5%)	0.59		2002-2005	NEC CORPORATION(76) KUBO YOSHIMI(19) YOSHITAKE TSUTOMU(19) MANAKO TAKASHI(15) KIMURA HIDEKAZU(15)	YOSHITAKE TSUTOMU(76) KIMURA HIDEKAZU(61) MANAKO TAKASHI(49) KUROSHIMA SADANORI(47) SHIMAKAWA YUICHI(42)
KIMURA HIDEKAZU	74 (1.4%)	0.473		2002-2007	NEC CORPORATION(74) KIMURA HIDEKAZU(17) MANAKO TAKASHI(16) KUBO YOSHIMI(15) YOSHITAKE TSUTOMU(15)	YOSHITAKE TSUTOMU(69) KUBO YOSHIMI(61) KUROSHIMA SADANORI(56) MANAKO TAKASHI(52) SHIMAKAWA YUICHI(44)
KWAK CHAN	71 (1.3%)	0.254		2004-2008	SAMSUNG GROUP(70) KIM HA SUCK(2)	LEE SI HYUN(40) MIN MYOUNG KI(26) ALEXANDROVICHSEROV ALEXEY(24) ALEXEY ALEXANDROVICHSEROV(18) KWEON HO JIN(14)
KWEON HO JIN	68 (1.3%)	0.515		2004-2007	SAMSUNG GROUP(67) KIM HA SUCK(2)	KIM HEE TAK(29) KWAK CHAN(14) KIM JAN DEE(13) LEE SI HYUN(13) KIM YOU MEE(12)
MANAKO TAKASHI	57 (1.1%)	0.246		2003-2007	NEC CORPORATION(57) MANAKO TAKASHI(17) KIMURA HIDEKAZU(16) KUBO YOSHIMI(15) YOSHITAKE TSUTOMU(15)	KIMURA HIDEKAZU(52) YOSHITAKE TSUTOMU(52) KUBO YOSHIMI(49) KUROSHIMA SADANORI(37) NAKAMURA SHIN(33)
KUROSHIMA SADANORI	56 (1.1%)	0.589		2002-2005	NEC CORPORATION(56) KIMURA HIDEKAZU(10) KUBO YOSHIMI(10) KUROSHIMA SADANORI(10) MANAKO TAKASHI(10)	KIMURA HIDEKAZU(56) YOSHITAKE TSUTOMU(56) KUBO YOSHIMI(47) SHIMAKAWA YUICHI(42) IMAI HIDETO(40)
LEE SI HYUN	49 (0.9%)	0.184		2005-2007	SAMSUNG GROUP(49)	KWAK CHAN(40) ALEXANDROVICHSEROV ALEXEY(19) ALEXEY ALEXANDROVICHSEROV(16) KWEON HO JIN(13) MIN MYOUNG KI(10)
CHIANG YET MING	47 (0.9%)	0.34		2001-2009	MASSACHUSETTS INSTITUTE OF TECHNOLOGY(33) A123 SYSTEMS INC.(12) CHIANG YET MING(8)	GOZDZ ANTONI S(14) CHIN TIMOTHY E(13) CHU ANDREW C(12) HELLWEG BENJAMIN(12) RILEY GILBERT N(10)
SAITO SHIN	47 (0.9%)	0.043		2007-2009	SUMITOMO GROUP(47) SAITO SHIN(7) KURODA RYUMA(6) KURITA HIROYUKI(5) SHINODA HIROSHI(4)	KURODA RYUMA(40) KURITA HIROYUKI(35) SHINODA HIROSHI(25) MASUI KENTARO(17) HIGASHIMURA HIDEYUKI(7)

SHIMAKAWA YUICHI	47 (0.9%)	0.681		2002-2004	NEC CORPORATION(47) IMAI HIDETO(8) KIMURA HIDEKAZU(8) KUBO YOSHIMI(8) KUROSHIMA SADANORI(8)	YOSHITAKE TSUTOMU(45) KIMURA HIDEKAZU(44) KUBO YOSHIMI(42) KUROSHIMA SADANORI(42) IMAI HIDETO(41)
NAKAMURA SHIN	45 (0.8%)	0.311		2003-2005	NEC CORPORATION(44) KUBO YOSHIMI(9) NAKAMURA SHIN(9) YOSHITAKE TSUTOMU(9) IMAI HIDETO(8)	YOSHITAKE TSUTOMU(43) KUBO YOSHIMI(37) KIMURA HIDEKAZU(36) SHIMAKAWA YUICHI(36) KUROSHIMA SADANORI(34)
IMAI HIDETO	42 (0.8%)	0.762		2002-2004	NEC CORPORATION(42) IMAI HIDETO(8) KIMURA HIDEKAZU(8) KUBO YOSHIMI(8) KUROSHIMA SADANORI(8)	YOSHITAKE TSUTOMU(42) SHIMAKAWA YUICHI(41) KIMURA HIDEKAZU(40) KUROSHIMA SADANORI(40) KUBO YOSHIMI(39)
SUDA YOSHIHISA	41 (0.8%)	0.39		2002-2009	MITSUBISHI PENCIL CO LTD.(41) CASIO COMPUTER CO LTD.(9) SUDA YOSHIHISA(6) KAMITANI TOSHIMI(5) OSADA TAKAHIRO(5)	OSADA TAKAHIRO(32) YAMADA KUNITAKA(28) KAMITANI TOSHIMI(23) NISHIMURA KOUJI(17) KABASAWA YASUNARI(11)
YAZAMI RACHID	41 (0.8%)	0.341		2003-2009	CALIFORNIA INSTITUTE OF TECHNOLOGY(41) CENTRE NAT RECH SCIENT(19) YAZAMI RACHID(10) UNIVERSITE BLAISE PASCAL(9) CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE (C.N.R.S.)(8)	HAMWI ANDRE(18) SHI QINGFANG(7) BUGGA RATNAKUMAR V(4) PRAKASH SURYA G(4) SMART MARSHALL C(4)

Inventors such as Yoshitake Tsutomo, Kubo Yoshimi, and Kimura Hidekazu were responsible for patents that were cited in several future patents in this space and can be considered critical in the development of the technology.

How we did it?

In order to compress all the information into a single report, we used the new 360° series of reports available in the software. From the Inventor 360° report options, we selected the different pieces of information we wanted to include in the singular display and then ran the report. The generated report was then exported to Excel using the option provided for the same.

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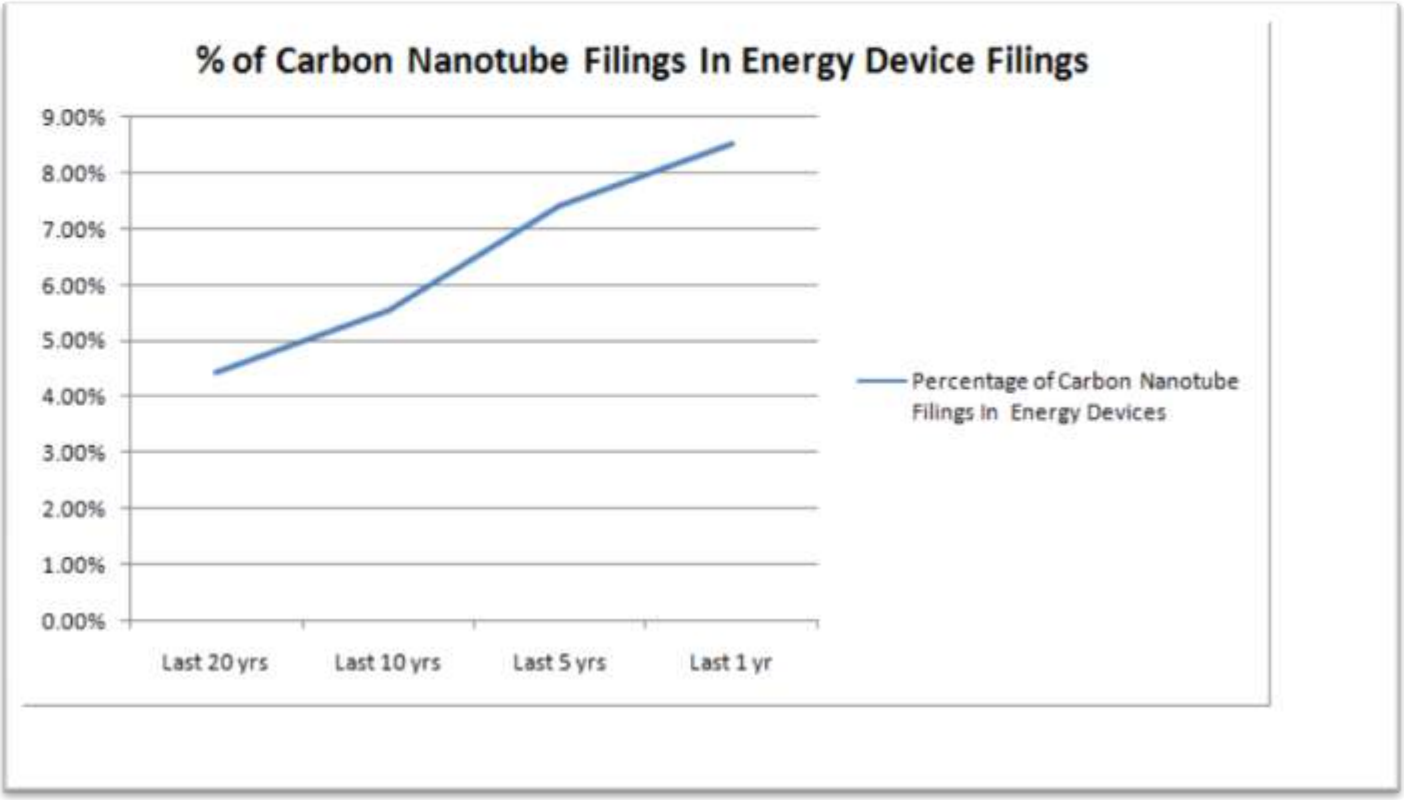
Percentage of Carbon Nanotube Filings in Energy Devices

What is the growth rate in percentage of carbon nanotube based filings vis-à-vis the total energy storage device filings?



The graph shows a steady increase in the filing activity for use of Carbon Nanotubes in Energy devices. Considering the growth of 8.5% in last year over the period of 2003-2007, the technology is poised for further growth.

How we did it?

We calculated the percentage of carbon nanotubes filings and the overall US Class 429 (Electrical Current Producing Apparatus) filings across different time spans. The percentage gathered for each time span was then display using a line chart in Excel.

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Energy Storage Device Trends

Energy Type	Energy Storage Devices	Total No. of Records	Average No.of Fwd Cites per Patents	Filing Trend (Absolute)	Filing Year Range	Top 5 Assignees	Top 5 Inventors
CHEMICAL ENERGY	Biofuels	10 (0.2%)	2.70		2001-2009	XEROX CORPORATION(3) SONY CORPORATION(3) CANON INC.(1) UNITED STATES OF AMERICA AS REPRESENTED BY THE ADMINISTRATOR OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION(1) UNIVERSITY OF CENTRAL FLORIDA RESEARCH FOUNDATION, INC.(1)	SWIFT JOSEPH A(3) WALLACE STANLEY J(3) SATO ATSUSHI(2) BUTLER MICHAEL A(2) NAKAGAWA TAKAAKI(2)
	Hydrogen	790 (14.8%)	1.28		1974-2010	SAMSUNG GROUP(73) BLACKLIGHT POWER INC.(36) SONY CORPORATION(35) NEC CORPORATION(25) TOYOTA GROUP(24)	MILLS RANDELL L(25) KWEON HO JIN(18) FUJII HIRONOBU(17) ICHIKAWA TAKAYUKI(16) EICKHOFF STEVEN J(15)
	Hydrogen Peroxide	77 (1.4%)	7.83		1991-2009	CITIBANK, N.A., AS COLLATERAL AGENT(8) SAMSUNG GROUP(7) RICE UNIVERSITY(5) NISSAN MOTOR CO LTD.(4) UNIVERSITY OF ST LOUIS(4)	YEAGER GARY WILLIAM(8) HELLER ADAM(7) GUO TING(5) HAFNER JASON H(5) LIU JIE(5)
	Liquid Nitrogen	1 (0%)	0.00		2006-2006	SAMSUNG GROUP(1)	KIM JI RAE(1) LEE SEOL AH(1) LEE SEUNG JAE(1) PAK CHAN HO(1) YOO DAE JONG(1)
	Oxyhydrogen	5 (0.1%)	11.20		2001-2005	DUPONT(2) XOLIOX SA(2) KOURTAKIS KOSTANTINOS(1) WANG LIN(1) FRANCOIS SUGNAUX(1)	GRAETZEL MICHAEL(3) PAPPAS NICHOLAS(3) SUGNAUX FRANCOIS(3) KOURTAKIS KOSTANTINOS(2) WANG LIN(2)
ELECTROCHEMICAL ENERGY	Batteries	1265 (23.8%)	1.29		1960-2009	NEC CORPORATION(80) PANASONIC CORPORATION(75) SAMSUNG GROUP(69) POLYPLUS BATTERY COMPANY(53) MASSACHUSETTS INSTITUTE OF TECHNOLOGY(29)	MORI MITSUHIRO(35) MIURA TAMAKI(34) UTSUGI KOJI(33) IRIYAMA JIRO(32) CHU MAY YING(24)
	Flow Batteries	186 (3.5%)	2.58		1987-2009	POLYPLUS BATTERY COMPANY(20) ALTAIRNANO INC.(9) RUTGERS, THE STATE UNIVERSITY OF NEW JERSEY(8) ENERGY CONVERSION DEVICES INC.(7) SAMSUNG GROUP(7)	CHU MAY YING(9) FIERRO CRISTIAN(8) HARRISON CRAIG(8) OVSHINSKY STANFORD R(8) SOMMERS BETH(8)
	Fuel Cells	2239 (42%)	0.70		1966-2010	SAMSUNG GROUP(393) TOYOTA GROUP(122) NEC CORPORATION(111) SONY CORPORATION(85) HONDA MOTOR CO LTD.(66)	YOSHITAKE TSUTOMU(85) KUBO YOSHIMI(76) KIMURA HIDEKAZU(71) KWAK CHAN(69) KWEON HO JIN(68)
ELECTRICAL ENERGY	Capacitor	172 (3.2%)	1.87		1992-2009	GREATBATCH INC.(9) MAXWELL TECHNOLOGIES INC.(8) LUXON ENERGY DEVICES CORPORATION(8)	NEFF WOLFRAM(9) SHAH ASHISH(9) XI XIAOMEI(8) SHIUE LIH REN(8) ZHONG LINDA(8)
	Supercapacitor	114 (2.1%)	1.29		1998-2009	MAXWELL TECHNOLOGIES INC.(8) LUXON ENERGY DEVICES CORPORATION(8) BOLLORE GROUP(6)	XI XIAOMEI(8) ZHONG LINDA(8) MIZUTA KEIICHIRO(6) WANG JING(6) SUN ABEL(6)
	Superconducting Magnetic Energy Storage (SMES)	5 (0.1%)	1.80		2003-2005	AMERICAN ENVIRONMENTAL SYSTEMS INC.(3) HETTIGE CHAMINDA(1) LEDDY JOHNA(1) UNIVERSITY OF IOWA	MALAK HENRYK(4) HETTIGE CHAMINDA(1) LEDDY JOHNA(1)

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MECHANICAL ENERGY	Compressed Air Energy Storage (CAES)	47 (0.9%)	2.13		1997-2009	SONY CORPORATION(4) MITSUBISHI PENCIL CO LTD.(4) WANG JING(3) FUELCELL TECHNOLOGIES INC.(3) MEDTRONIC INC(3)	WANG JING(8) MARUYAMA RYUICHIRO(4) MIYAZAWA HIROSHI(4) KAMITANI TOSHIMI(4) NISHIMURA KOUJI(4)
	Flywheel Energy Storage	3 (0.1%)	0.00		2001-2002	LUXON ENERGY DEVICES CORPORATION(1)	HSIEH FEI-CHEN(2) HSIEH YU-HIS(2) JOU JIUNG-JAU(2) SHIUE CHIA-CHANN(2) SHIUE LIH-REN(2)
	Hydraulic Accumulator	3 (0.1%)	0.67		2003-2005	MASSACHUSETTS INSTITUTE OF TECHNOLOGY(2) RHYNER URS(1) SAPNARAS DIMITRIOS(1) SONG KYUNGYEOL(1) TUBILLA FERNANDO(1)	HALL STEVEN R(2) KOYAMA YUKINORI(2) RHYNER URS(2) SAPNARAS DIMITRIOS(2) SONG KYUNGYEOL(2)
	Hydroelectric Energy Storage	6 (0.1%)	2.17		2003-2008	ION AMERICA CORPORATION(3) BLOOM ENERGY CORPORATION(2) SRIDHAR K R(1) ANDERSON ROSS(1) ARJMANDI MOSAYYEB(1)	GOTTMANN MATTHIAS(3) MITLITSKY FRED(3) SRIDHAR K R(3) FINN JOHN E(2) MCELROY JAMES F(2)
	Spring	20 (0.4%)	1.55		2001-2009	EVEREADY INDUSTRIES(2) ANGSTROM POWER INC.(2) ZIMMERMANN JOERG(1) CHOU, SHERRY(1) CLEANTECH GROUP(1)	MOHRING RICHARD M(2) MARPLE JACK W(2) STRIZKI MICHAEL(2) ADAMS PAUL(2) CURELLO ANDREW J(2)
THERMAL ENERGY	Cryogenic Liquid Air Or Nitrogen	3 (0.1%)	4.33		2002-2006	KEEFER BOWIE(2) ST PIERRE JEAN(1) SAMSUNG GROUP(1) KNIGHTS SHANNA D(1) NELSON AMY E(1)	KEEFER BOWIE G(2) KNIGHTS SHANNA D(2) NELSON AMY E(2) ROY SURAJIT(2) ST PIERRE JEAN(2)
	Eutectic System	5 (0.1%)	2.40		2004-2009	CANON INC.(3) LG CORPORATION(2) YAMADA KAZUHIRO(1) ASAO MASAYA(1) KAWAKAMI SOICHIRO(1)	KAWAKAMI SOICHIRO(3) KIM YOUNG MIN(2) OH EUN SUOK(2) RYU MINJUNG(2) YANG SEUNGRIM(2)
	Heat Storage	5 (0.1%)	0.00		2003-2005	GOTTMANN MATTHIAS(3) ION AMERICA CORPORATION(3) MITLITSKY FRED(2) SRIDHAR K R(2) MCELROY JAMES(2)	SRIDHAR K(2) FINN JOHN(1) GOTTMANN MATTHIAS(1) MCELROY JAMES(1) MITLITSKY FRED(1)
	Molten Salt	13 (0.2%)	1.23		1991-2005	TOYOTA GROUP(8) LI WEN(5) OYAMA YUTAKA(4) MATSUI MASAKI(3) AABH PATENT HOLDINGS(3)	LI WEN(8) OYAMA YUTAKA(7) MATSUI MASAKI(6) AWANO HIROAKI(2) PERRON GERALD(2)
	Solar Cell	54 (1%)	5.48		1998-2009	FUJIKURA LTD.(18) RICE UNIVERSITY(10) NANOSOLAR INC(10) ION AMERICA CORPORATION(3) MCELROY JAMES(2)	MATSUI HIROSHI(12) TANABE NOBUO(12) RINZLER ANDREW G(7) SMALLEY RICHARD E(7) THESS ANDREAS(7)
	Steam Accumulator	39 (0.7%)	2.90		1997-2008	BATTELLE MEMORIAL INSTITUTE(8) NEC CORPORATION(5) IDATECH LLC(5) SAMSUNG GROUP(3) SONY CORPORATION(3)	CHIN YA HUEI(8) HOLLADAY JAMELYN D(8) WANG YONG(8) PHELPS MAX R(7) EDLUND DAVID J(5)

The chart shows the filing trend as well as the key Assignees and Inventors in each energy storage device. Electrochemical energy storage devices, which include batteries, flow batteries and fuel cells is the most active technical sector according to the filing trends.

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How we did it?

In order to compress all the information into a single report, we used the new 360° series of reports available in the software. From the Technology 360° report options, we selected the Energy Storage Device categorization that we had made earlier and then ran the report. The generated report was then exported to Excel using the option provided for the same.

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Carbon Nanotubes Properties vs. Energy Storage Devices

How various properties of Carbon nanotubes are leveraged across Energy Storage Devices?

ENERGY STORAGE DEVICES (Column) / PROPERTIES (Rows)	Total	Electrochemical				Chemical					Electrical				Thermal					Mechanical				
		Total	Fuel Cells	Flow Batteries	Batteries	Total	Hydrogen	Oxyhydrogen	Hydrogen Peroxide	Biofuels	Total	Supercapacitor	Capacitor	Superconducting Magnetic Energy Storage (SMES)	Total	Steam Accumulator	Solar Cell	Molten Salt	Eutectic System	Total	Compressed Air Energy Storage (CAES)	Flywheel Energy Storage	Hydraulic Accumulator	Spring
Total	1025	922	592	81	384	288	257	5	25	5	104	54	78	5	44	13	19	8	3	53	30	3	3	18
Mechanical Properties	461	420	250	44	187	113	102	1	11	1	50	28	40	1	18	3	12		3	34	20	3	3	11
Density	375	343	195	42	164	81	74		8	1	43	23	35	1	14	3	10		1	19	13	3	2	4
Flexible	62	55	43	2	14	26	24	1	1		6	3	4		1		1			16	7		2	7
Tensile and Compressive Strength	18	16	12		4						2	2	2							1		1		1
Young Modulus	12	12	10		2	2	2																	
Conductive Properties	400	360	242	37	137	109	92	5	12	3	55	30	37	4	19	6	6	6	1	22	12	3	3	9
Electrical Conductivity	320	286	191	34	109	84	67	5	11	3	45	26	27	4	15	2	6	6	1	16	7	3	2	7
Heat Conductivity	43	37	26	2	13	24	21		3		6		6		4	4				5	5			2
High Current Density	20	19	17	2	4	2	2		1		4	3	4		1				1	1				1
Field Emission	10	10	10		3	2	2		1		3	2	3											
Anisotropic Thermal Conductivity	8	6	4		2															2			2	
Physical Properties	371	325	198	38	156	132	118	3	11	4	44	23	33	5	27	11	11	2	3	23	14	3		10
Ability to be Manipulated	76	64	39	19	37	29	26		3	1	3	2	2		5	2	3			10	5			5
Hardness	51	47	23	4	24	10	10				4	1	2	2	1			1		5	2			2
Impervious to Environmental Factors	45	38	26	4	20	28	23		6	1	13	4	8	4	7	3	3		1	3	2			1
Stength	40	35	23	2	15	17	13	1	3		7	6	5	1	4	2			2	1	1			
Electronic Structure	35	31	16	4	16	9	7	2			8	4	6		1	1				2	2			
Toxicity	13	13	8	1	6	7	7		1		4	1	4							1		1		1
One-Dimensional Transport	15	13	5	3	9	2	2				4	3	3		1	1								

Chemical-Biochemical Properties	85	77	65	5	43	30	29	1	1	2	16	11	13	1	7	2	4			6	5	2		3
High Specific Surface Area	50	46	39	5	25	20	19	1	1	1	14	11	12		2		2			5	4	2		3
Capillarity	30	29	27	1	16	10	10		1		2		2		2	1								
Electrical Properties	37	33	17	11	21	10	7		3		12	3	11		2		2			3	2	1		1
Optical Properties	14	10	9	3	8	6	5		2		8	3	6	1										
Absorption	9	5	4	1	4	1	1		1		8	3	6	1										
Photoluminescence	2	2	2		2	2	2																	
Raman Spectroscopy	1	1	1			1			1															
Thermal Properties	5	5	3		2	3	3				2	2												
Ballistic Conduction	2	2			2	2	2				2	2												
Magnetic Properties	12	5	3	1	3	7	7		1		3	2	1	1	1				1	6		1		3
Magnetic Field	10	4	2	1	2	5	5		1		3	2	1	1	1				1	5		1		2
Paramagnetic	3	1	1		1	2	2				1			1						1				1
Ferromagnetic	1										1			1										
Diamagnetic	1					1	1													1				1
Defects	4	2			2	4	1		3						2		2							
Schottky Defect	4	2			2	4	1		3						2		2							

This kind of an analysis can help various companies understand to what extent a particular property has been utilized across energy storage devices and if there is any further scope of innovation. This analysis also helps one to locate whitespace in this technology area. The insights from the analysis can directly influence technology managers' decision to conduct research in poorly patent protected technology areas to eventually become market leaders in that space.

How we did it?

We manually created categories of carbon nanotube properties and energy storage devices. A two-level categorization was done in both the cases. Then using the co-occurrence matrix, a map was generated for properties vs. energy storage device.

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Carbon Nanotubes - Types vs. Properties

What properties are used across different types of Carbon nanotubes?

Types of Carbon Nanotubes (Rows) Properties (Column)	Total	Single-wall Nanotubes (SWNT)	Multi-wall Nanotubes (MWNT)	Fullerene Nanotubes	Double-wall Nanotubes (DWNT)	Cup Stacked Carbon Nanotubes
Total	98	57	36	33	5	1
Physical Properties	43	29	19	13	2	
Impervious to Environmental Factors	11	9	4	2		
Ability to be Manipulated	11	10	6	1		
Stength	6	2	2	4		
Electronic Structure	6	3	1	3	1	
One-Dimensional Transport	5	3	4		1	
Toxicity	3	3	2			
Hardness	2	1	1	1		
Mechanical Properties	42	24	20	12	3	1
Density	36	22	17	9	3	1
Flexible	3		1	2		
Tensile and Compressive Strength	2	1		1		
Conductive Properties	41	22	8	20		
Electrical Conductivity	39	20	7	20		
High Current Density	2	2				
Heat Conductivity	1	1				
Field Emission						
Chemical-Biochemical Properties	17	6	8	10		
High Specific Surface Area	12	5	7	6		
Capillarity	3	2	2	1		
Optical Properties	9	9	4			
Electrical Properties	9	8	2	1		
Magnetic Properties	7	7	2		1	
Magnetic Field	7	7	2		1	
Defects	4	3		1		
Schottky Defect	4	3		1		

In the above matrix leading patent holdings within each category of carbon nanotube types have been highlighted with stronger shades of green for larger number of patents within that category. One can see that high electrical conductivity of Fullerene nanotubes have been targeted in many patents.

How we did it?

We manually created categories of carbon nanotube properties and types. A two-level categorization was done in case of Properties. Then using the co-occurrence matrix, a map was generated for properties vs. types.

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Assignee Portfolio spread across different Energy Storage Devices

Energy Storage Devices (Columns) / Key Assignees (Rows)	Total	Chemical						Electrochemical				Thermal							Electrical			Mechanical					
		Total	Hydrogen	Hydrogen Peroxide	Biofuels	Oxyhydrogen	Liquid Nitrogen	Total	Batteries	Fuel Cells	Flow Batteries	Total	Solar Cell	Steam Accumulator	Molten Salt	Heat Storage	Eutectic System	Cryogenic Liquid Air Or Nitrogen	Total	Capacitor	Supercapacitor	Total	Compressed Air Energy Storage (CAES)	Flywheel Energy Storage	Hydraulic Accumulator	Hydroelectric Energy Storage	Spring
Total	2934	680	635	41	4	2	1	2671	914	1854	125	102	47	34	10	5	5	1	120	109	64	41	21	1	2	5	7
3M	18	3	3					17	2	15	2								1	1							
A123 SYSTEMS INC.	19	1	1					19	19																		
ALTAIRNANO INC.	10							10	10		9																
ANGSTROM POWER INC.	24	16	16					17	1	17												4	2				2
ASAHI KASEI CORPORATION	16	5	5					15		15																	
BALLARD POWER SYSTEMS INC.	10							10		10																	
BASF GLOBAL	16	8	8					13	1	13	1																
BATTELLE MEMORIAL INSTITUTE	19	8	8					9	1	8		8		8													
BLACKLIGHT POWER INC.	38	36	36					8	6	7	2	2		1								1					1
BLOOM ENERGY CORPORATION	10	7	7					10		10		3	2			1						2				2	
BROOKHAVEN SCIENCE ASSOCIATES	11	7	7					11		11																	
CABOT CORPORATION	13	8	8					9		9									2	2							
CALIFORNIA INSTITUTE OF TECHNOLOGY	33	8	8					31	21	10	3								5		5						
CANON INC.	66	14	12	2	1			66	21	50	2	4		1			3		1	1	1	1					1
CASIO COMPUTER CO LTD.	38	6	6					36	3	33		2		2					1	1		1	1				
CATALER CORPORATION	9	1	1					9	2	7																	
CENTRE NAT RECH SCIENT	21	5	5					18	15	3	1	1			1				4	1	3						
COMMISSARIAT A LENERGIE ATOMIQUE	39	3	3					37	17	22																	
COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH OR...	8							7	7										8	8	2						
DAINIPPON PRINTING CO LTD.	9							9		9																	
DUPONT	30	11	6	3		2		29	7	22																	
ELECTRICITE DE FRANCE	10							9	9										1	1	1						
ENERGY CONVERSION DEVICES INC.	20	11	11					12	6		7																

ENTEGRIS INC.	16	1		1				16		16																	
EVEREADY INDUSTRIES	26							26	26	3												2					2
EVONIK INDUSTRIES	12	2	2					12		12																	
FMC CORPORATION	17							17	17		3																
FRAUNHOFER-GESELLSCHAFT	9							8	6	2	2	1		1													
FUELCELL TECHNOLOGIES INC.	17	14	14					4		4									3	3		3	3				
FUJI HEAVY INDUSTRIES LTD.	15	2	2					15	15										3	3							
FUJIFILM CORPORATION	51	22	22					51	2	49																	
FUJIKURA LTD.	20							2	2			18	18		1												
GENERAL ELECTRIC	23	19	17	2				9	4	9	4								1		1						
GENERAL MOTORS COMPANY	27	3	3					27	5	25																	
GREATBATCH INC.	12							3	3										9	9							
GSI CREOS CORPORATION	14							11	11										3	3	3						
HAVE BLUE LLC	12	12	12					2	2	2		2		2													
HIGH POWER LITHIUM S A	8	2	2					8	2		7																
HITACHI LTD.	38	20	18	2				29	1	28									1	1							
HITACHI MAXELL LTD.	17	1	1					16	2	14									2	2	2						
HON HAI PRECISION INDUSTRY CO LTD.	17							17	11	7	1																
HONDA MOTOR CO LTD.	70	2	2					66	2	66									3	3	2						
HONEYWELL INTERNATIONAL INC.	30	22	22					26	10	26	6								7	7	5						
HYPERION CATALYSIS INTERNATIONAL INC.	8							8	8		1																
IDATECH LLC	16	15	15					16		16		5		5								2	2				
INFINITE POWER SOLUTIONS INC	17							17	17																		
INTEGRAN TECHNOLOGIES INC.	16							16	16																		
ION AMERICA CORPORATION	15	9	9					14		14		6	3			3						5				3	
KOREA INSTITUTE OF SCIENCE AND TECHNOLOGY	8	1	1					6	5	2		1	1						5	3	5						
KOREA KUMHO PETROCHEMICAL CO LTD.	8	2	2					8	8																		
LG CORPORATION	47	2		2				47	22	25	4	2					2		1	1	1						
LUXON ENERGY DEVICES CORPORATION	8							4	4	2		2	2						8	8	8	1	1	1			
MASSACHUSETTS INSTITUTE OF TECHNOLOGY	35	1	1					32	29	3	4	1		1					2	2		3	1		2		
MAXWELL TECHNOLOGIES INC.	8																		8	8	8						

METALLIC POWER INC.	14	4	4					14	4	14	2																
MITSUBISHI GROUP	32							29	8	21	2	2		2					8	8	5						
MITSUBISHI MATERIALS CORPORATION	17	1	1					17	6	11	1																
MITSUBISHI PENCIL CO LTD.	60							60	13	53												4	4				
MITSUI GROUP	19	4	4					19	12	7									2	2							
MORE ENERGY LTD.	30	14	14					30		30																	
MOTOROLA INC.	27	13	13					27	5	22																	
NANOSOLAR INC	10											10	10														
NANOSYS INC.	22	3	3					17	2	17									7	7	2						
NEC CORPORATION	185	25	25					185	80	111	4	5		5								4					
NEC TOKIN CORPORATION	9	4	4					9	6	3																	
NICHIAS CORPORATION	18	3	3					18		18																	
NIPPON CHEMICAL INDUSTRIAL CO LTD.	12							11	8	3		1			1				4	4	4						
NISSAN MOTOR CO LTD.	62	18	14	4				61	24	39																	
OHIO UNIVERSITY	12	12	12					7	3	7																	
OYAMA NOBORU	8	1	1					8	8										1	1							
PANASONIC CORPORATION	127	17	17					121	75	49	7								5	5	5						
POLAROID CORPORATION	14	4	4					14	14																		
POLYPLUS BATTERY COMPANY	53							53	53		20																
PROTON ENERGY SYSTEMS INC.	8	5	5					1		1												2	1				1
QUALLION LLC	10	7	5	2				8	7		1								3	3							
QUANTUMSPHERE INC.	18	13	13					18	8	18												1	1				
RICE UNIVERSITY	24	10	5	5				15	15			10	10						3	3							
RUTGERS, THE STATE UNIVERSITY OF NEW JERSEY	11							11	11		8																
SAMSUNG GROUP	454	81	73	7			1	451	69	393	7	5	1	3				1	2	2	1	2	2				
SEIKO GROUP	32							32	5	28																	
SHIROUMA SCIENCE CO LTD.	12	2	2					12	12										2	2							
SHOWA DENKO GROUP	73	4	1	3				73	24	59									4	4							
SONY CORPORATION	102	38	35	1	3			97	10	85	5	3		3					1	1		4	4				
STANFORD UNIVERSITY	47	1		1				47	6	42	2																
STMICROELECTRONICS	16	10	10					16	8	16																	
SUMITOMO GROUP	55	2	2					55	18	38	2																
TAIHEIYO CEMENT CORPORATION	17	17	17					1		1																	
TECHNICAL UNIVERSITY OF DENMARK	8							8		8																	

THE KURITA GROUP	8	1	1					8	1	7																	
TOMOEGAWA CO LTD	11							11	1	11																	
TOPPAN GROUP	14	3	3					14		14																	
TORAY INDUSTRIES INC.	13	2	2					13		13																	
TOSHIBA CORPORATION	34	8	7	1				34	1	34																	
TOYOTA GROUP	146	27	24	3				144	24	122	4	9			8	1											
TRULITE INC.	9	9	9	1				4		4									2	2							
TSINGHUA UNIVERSITY	17							17	11	8																	
UMICORE GROUP	14							14		14																	
UNITED STATES DEPARTMENT OF ENERGY	12	6	5	1				12	6	5	2								2	2							
UNIVERSITY OF CALIFORNIA	17	6	6					13	3	10																	
UNIVERSITY OF NORTH CAROLINA	11							11	11																		
UNIVERSITY OF PENNSYLVANIA	14	10	10					13		13																	
ZEON CORPORATION	11	1	1					11	11																		

This chart helps get an insight into some of the Energy storage device along with a listing of the top assignees in each category. It highlights the focus areas within the energy storage device being pursued by each company.

From the output it is clear that Samsung Group dominates in the fuel cells sub category with the maximum IP records.

How we did it?

We used the Co-occurrence analyzer in Patent iNSIGHT Pro to generate a matrix of Assignee vs. Energy Storage Devices. The generated matrix was then filtered for the top 100 Assignees and then exported to Excel.

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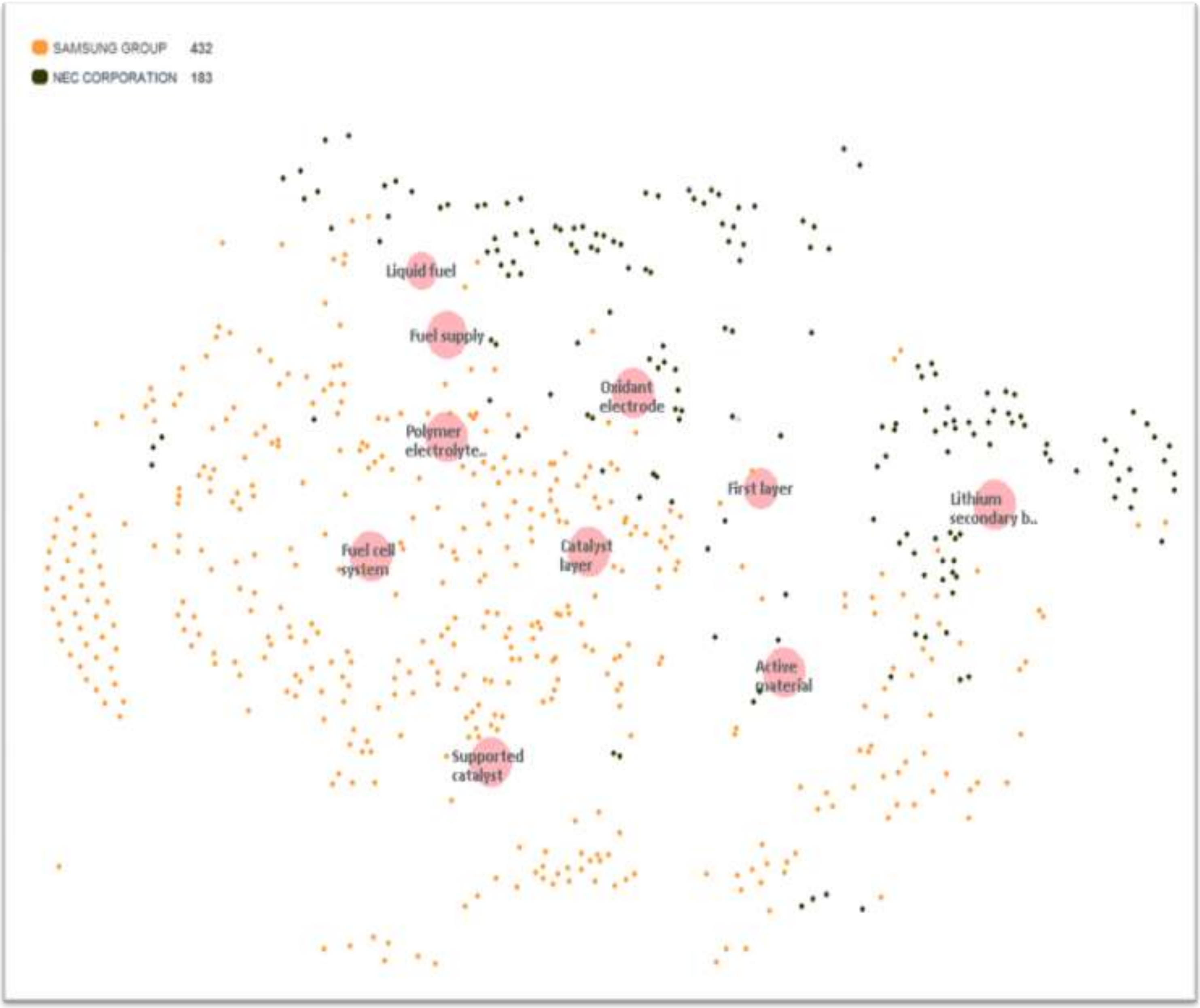
Sample Portfolio Comparison of NEC Corporation vs. other top Assignees

How does the portfolio landscape of NEC Corporation compare with other companies? What are the overlaps in the portfolios?

NEC Corporation vs. Samsung Group



The map shows patents of NEC and Samsung clustered together based on their IP Portfolio. The chart also shows the overlapping areas and patents in the two portfolios.

How we did it?

The VizMAP tool in Patent iNSIGHT Pro was used for this analysis. First the patents of the two assignees were loaded on the map. The map was then analyzed in the context mode wherein each patent record is placed across to the contextual similarity with other records. The contextual similarity was calculated over Title, Abstract and Claims.

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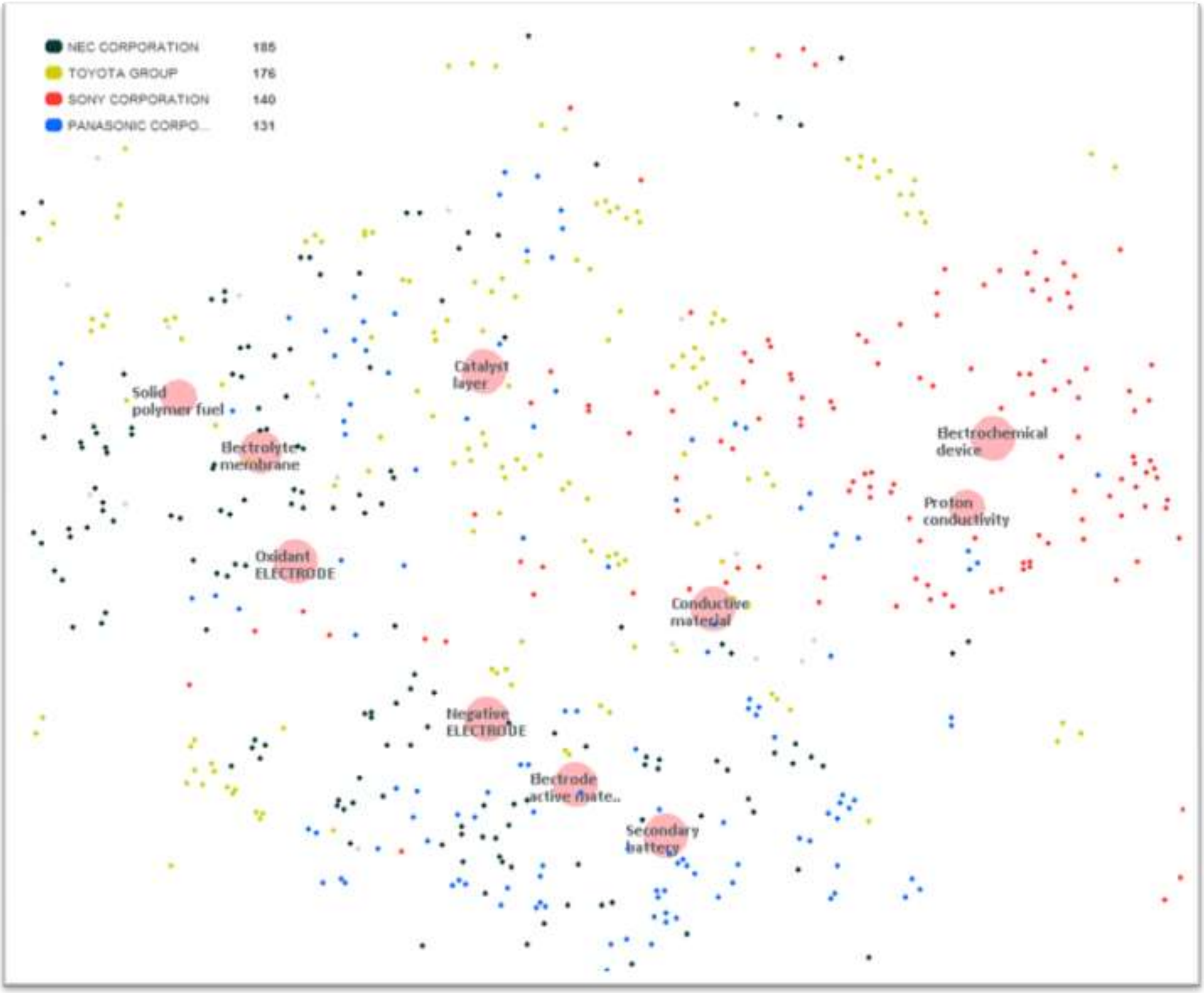
NEC Corp vs. Toyota, Sony and Panasonic



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Appendix A: Key Assignee Normalization Table

SAMSUNG GROUP
SAMSUNG GROUP
KIM HA SUCK

NEC CORPORATION
NEC CORPORATION
KATO KOMEI
IRIYAMA JIRO
SATOH MASAHARU
KONO YASUTAKA
SEKINO SHOJI

TOYOTA GROUP
HIRAMATSU MINEO
HORI MASARU
TOYOTA GROUP
TSUCHIYA CO LTD.
CATALER CORPORATION
SEI CORPORATION
JFE GROUP
SAITO TAKAMITSU

SONY CORPORATION
SONY CORPORATION
WATANABE MITSUHIRO

PANASONIC CORPORATION
PANASONIC CORPORATION
SUGOU MASAYO HF
HERLE P SUBRAMANYA

SHOWA DENKO GROUP
SHOWA DENKO GROUP

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
BELCHER ANGELA
CHIN TIMOTHY E
CARTER W CRAIG
CHIANG YET MING
DUDUTA MIHAI
HO BRYAN Y

ENERGY CONVERSION DEVICES INC.
ENERGY CONVERSION DEVICES INC.

POLYPLUS BATTERY COMPANY
POLYPLUS BATTERY COMPANY
JONGHE LUTGARD C DE

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Appendix B: Search Strings Used for Classification

Categorization: Types of carbon nanotubes

1. Single wall

Single Wall Nanotubes	
(SWNT* or (single w/3 wall*))	118 results
chiral*	5 results

2. Double wall

Double Wall Nanotubes	
DWNT* or ((dual* or double*) w/3 wall*)	14 results

3. Multi wall

Multi Wall Nanotubes	
(MWNT* or (multi w/3 wall*))	62 results

4. Fullerene Nanotubes

Fullerene Nanotubes	
(*WNT* or nanotube%) w/5 fulleren*	62 results

5. Cup Stacked Nanotube

Cup Stacked Nanotubes	
cup w/2 stack*	1 result

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Categorization: Properties of carbon nanotubes

1. Chemical- Biochemical Properties

Chemical Biochemical Properties	
(chemical or biochemical%) w/2 propert*	3 results
(chemical or biochemical%) w/3 propert*	10 results
capillar*	32 results
high* w/3 area*	71 results
high* w/5 (surface* w/2 area)	69 results

2. Conductive Properties

Conductive Properties	
conduct* w/2 propert*	23 results
anisotrop*	13 results
electric* w/3 conduct*	377 results
field emission	10 results
heat* w/3 conduct*	48 results
high* w/3 (current w/2 density)	20 results

3. Defects

Defects	
Schottky Defects	4 results

4. Electrical Properties

Electrical Properties	
Elec* w/2 propert*	44 results

5. Magnetic Properties

Magnetic Properties	
magnet* w/2 propert*	1 result
diamagnet*	1 result
ferromagnet*	1 result
magnet* w/2 field*	13 results
paramagnet*	5 results

6. Mechanical Properties

Mechanical Properties	
Mechanic* w/2 propert*	19 results
aclm contains densit*	184 results
densit*	425 results
aclm contains (flexibility or flexibl* or elastic* or stretch*)	82 results
Tensil* w/2 strength*	15 results

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tensil* w/2 modul*	13 results
young* w/2 modul*	10 results

7. Optical Properties

Optical Properties	
optic* w/2 propert*	3 results
optic* w/10 (absorb* or absorption*)	10 results
photolumi*	6 results
raman w/2 spectro*	4 results

8. Physical Properties

Physical Properties	
physic* w/2 propert*	11 results
aclm contains manipulat*	10 results
manipulat*	86 results
electric* w/5 structure*	37 results
electronic* w/5 structure*	3 results
aclm contains hard*	32 results
hard* or rough*	101 results
aclm contains hard* or rough*	54 results
spec contains environment*	5 results
aclm contains environment*	46 results
one w/2 dimension*	24 results
aclm contains strength*	44 results
toxic*	15 results
aclm contains toxic*	5 results

9. Thermal Property

Thermal Property	
thermal* w/2 propert*	3 results
ballistic*	2 results

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Categorization: Energy Storage Devices

1. Chemical

Chemical	
bio* w/2 fuel*	4 results
(biomass or (liquid w/2 fuel*) or biogas*) or bio w/2 fuel*	160 results
hydrogen and not (oxyhydrogen or peroxide)	790 results
(hydrogen w/2 peroxide) or H2o2	36 results
peroxide or (hydrogen w/2 peroxide*) or H2o2	77 results
(liquid* w/2 nitrogen) or LN2	1 result
Oxyhydro*	5 results

2. Electrical

Electrical	
capacitor* or (condenser* or condensor*)	172 results
supercapacitor or super- capacitor	57 results
super w/2 capacit*	11 results
supercapacitor*	64 results
(EDLC* or (ultra* or super* or pseudo* or double-layer) w/2 capacitor) or super-condenser	53 results
(EDLC* or (ultra* or super* or pseudo* or electrochemical*) w/2 capacitor) or super-condenser	34 results
Electric double-layer capacitor or supercapacitor or supercondenser or pseudocapacitor or electrochemical double layer capacitor or EDLC or ultracapacitor	2281 results
Electric double-layer capacitor or supercapacitor or supercondenser or pseudocapacitor or electrochemical double layer capacitor or EDLC or ultracapacitor	74 results
(super w/2 conduct*) or superconduct* and magnet*	5 results
superconducting and magnet*	2 results
superconductor and magnet*	3 results

3. Electrochemical

Electrochemical	
Batter*	1265 results
(flow or recharge*) w/3 (batter* or cell)	186 results
fuel w/3 cell*	2239 results

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4. Mechanical

Mechanical	
flywheel*	3 results
Spring*	27 results
aclm contains spring*	18 results
spec contains spring*	3 rresults
hydro* w/2 electric*	30 results
(ttl to Attorney Opinion) contains (hydro* w/2 electric*)	10 results

5. Thermal

Thermal	
stor* w/2 heat*	5 results
molt* w/3 salt*	13 results
steam* or mist*	39 results
solar* w/2 cell*	54 results
cryogen*	3 results
liquid* w/3 nitrogen*	1 result

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Summary

The leap in R&D activity and innovation in carbon nanotubes makes it evident that it can well be a part of the technologies we use in our day to day lives. It's unique properties and unparalleled nano structure makes it a crucial element for energy storage devices of the future which need to be able to compete with increased capacity at decreasing sizes just as the devices we use move in the same direction.

Carbon nanotubes have been picking up momentum in the markets as well and from the top assignees list it's clear that the most dominant technology and electronics companies intend to pursue their research around what could well be what powers our future.

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