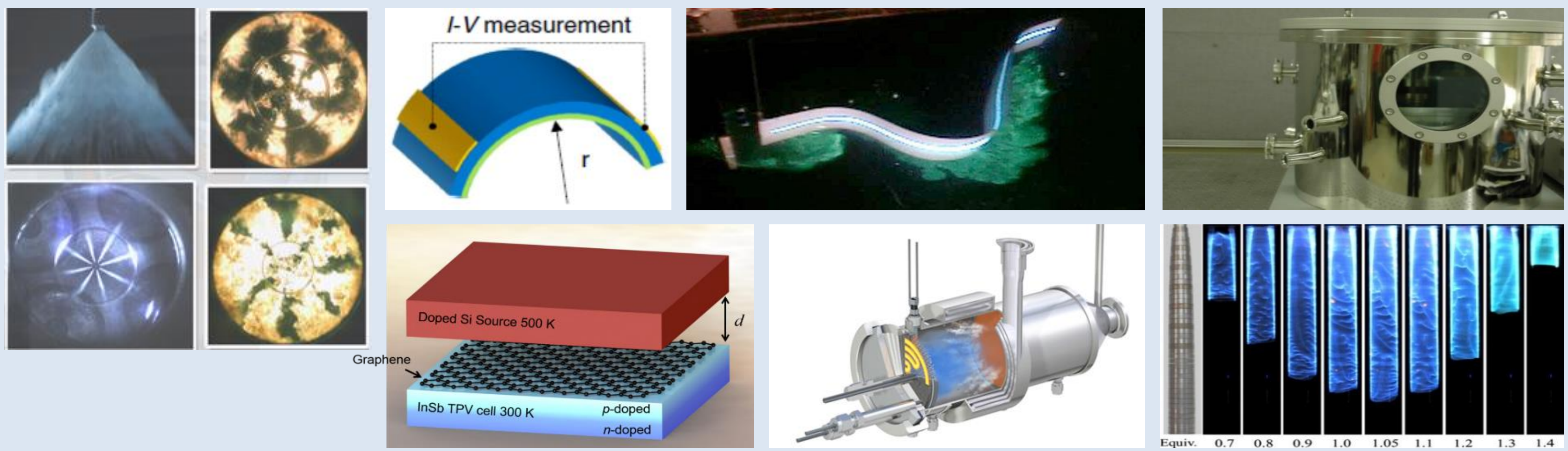
KAIST Korea Advanced Institute of Science and Technology

Engineering for Value Creation

Vision of Energy Sustainability



Choongsik Bae

Head, Dept. of Mechanical Engineering, KAIST

2016 International Forum Korea on Advances in Mechanical Engineering, Hotel ICC, Daejeon

Contents

History of IEA ETP 2050

In ETP 2050 (2006, 2008) three scenarios are considered

BLUE MAP	ACT MAP	Base Line
Half of CO_2 emissions of 2005	Same levels of CO2 emissions of 2005	CO2 emissions would be doubled

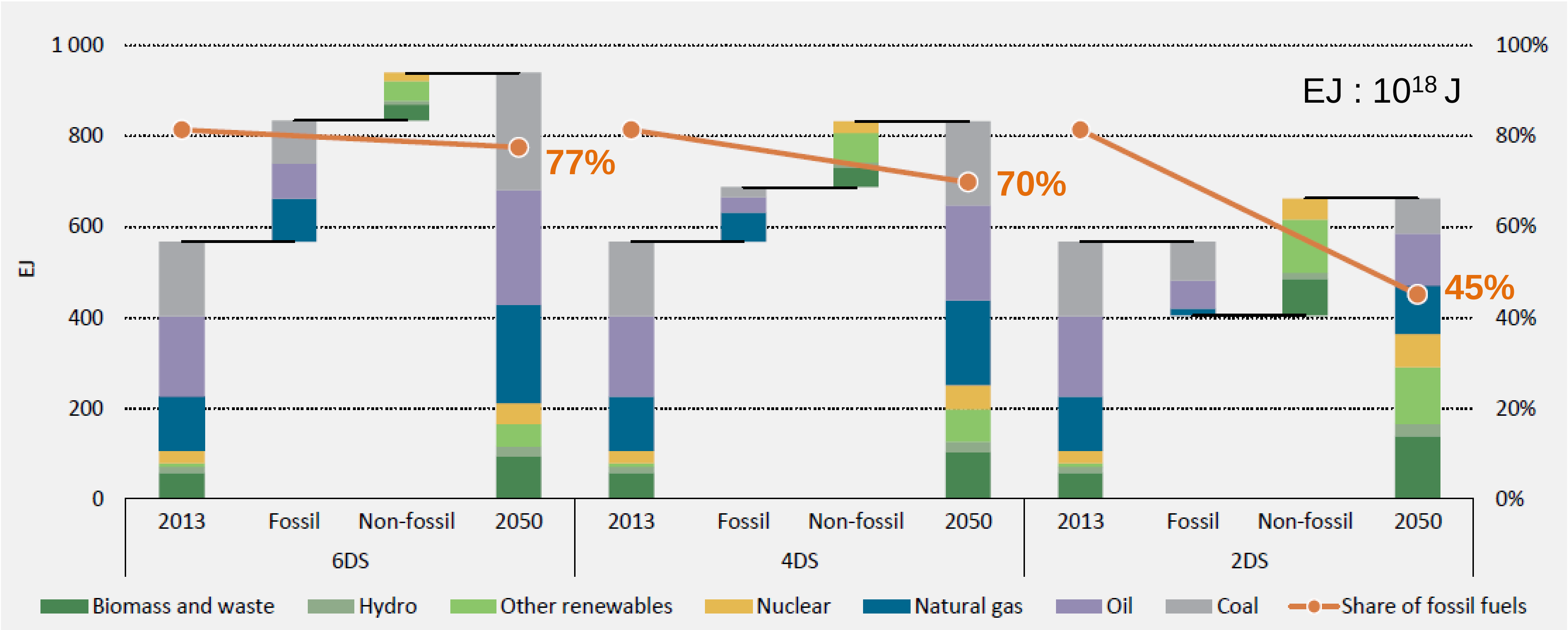
***In ETP 2050 (2010) only BLUE MAP is considered**

In ETP 2050 (2012, 2014, 2015, 2016) three scenarios are considered again, but changed

2DS	4DS	6DS
The 2^oC Scenario	The 4^oC Scenario	The 6^oC Scenario

- **Two major recent developments to make changes from ETP 2016**
  - Climate change agreement negotiated in 2015 at COP21 (Conference of Parties)
  - Low fossil fuel prices

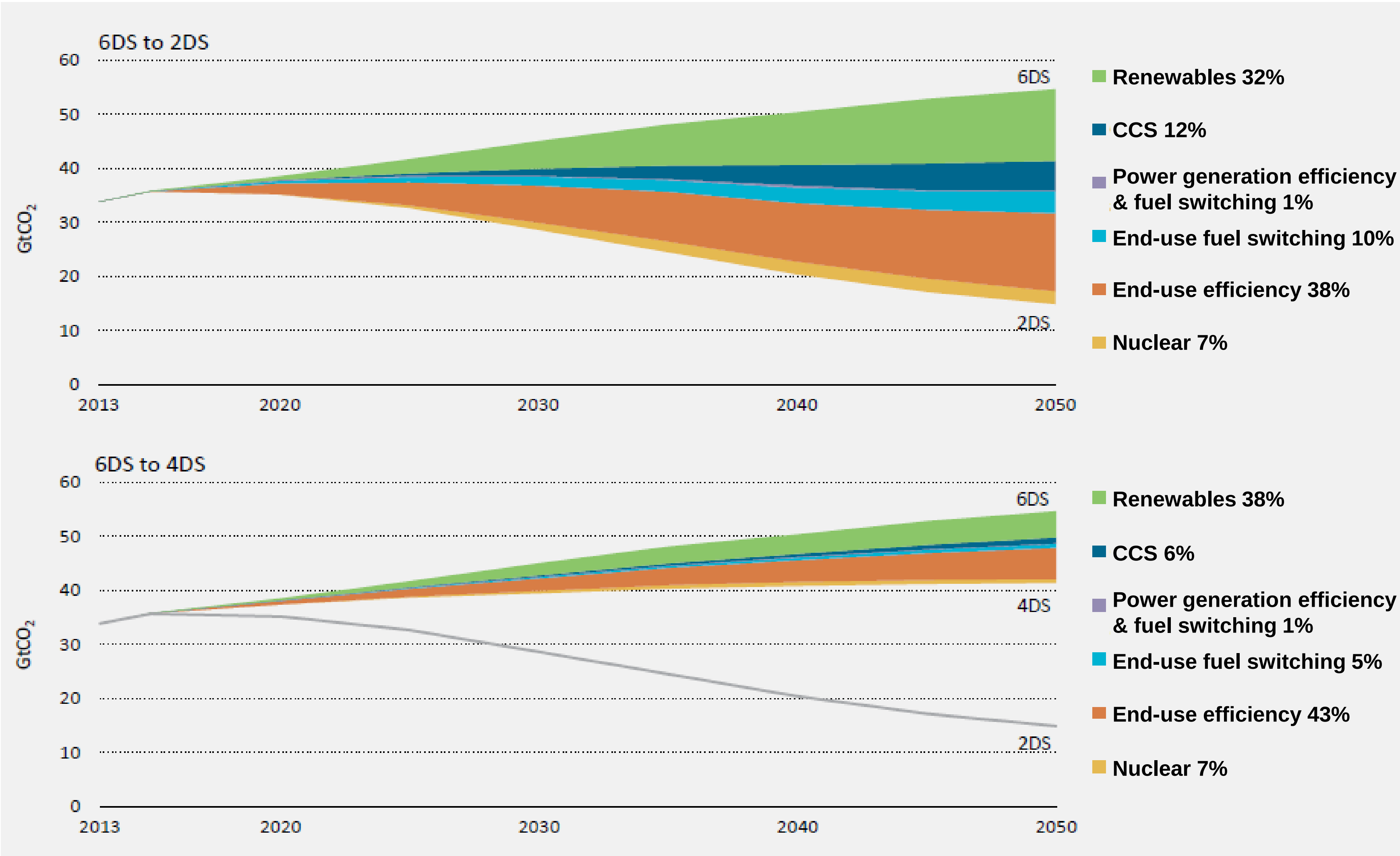
Global Primary Energy Use, 2013 to 2050



Source : ETP 2016, IEA

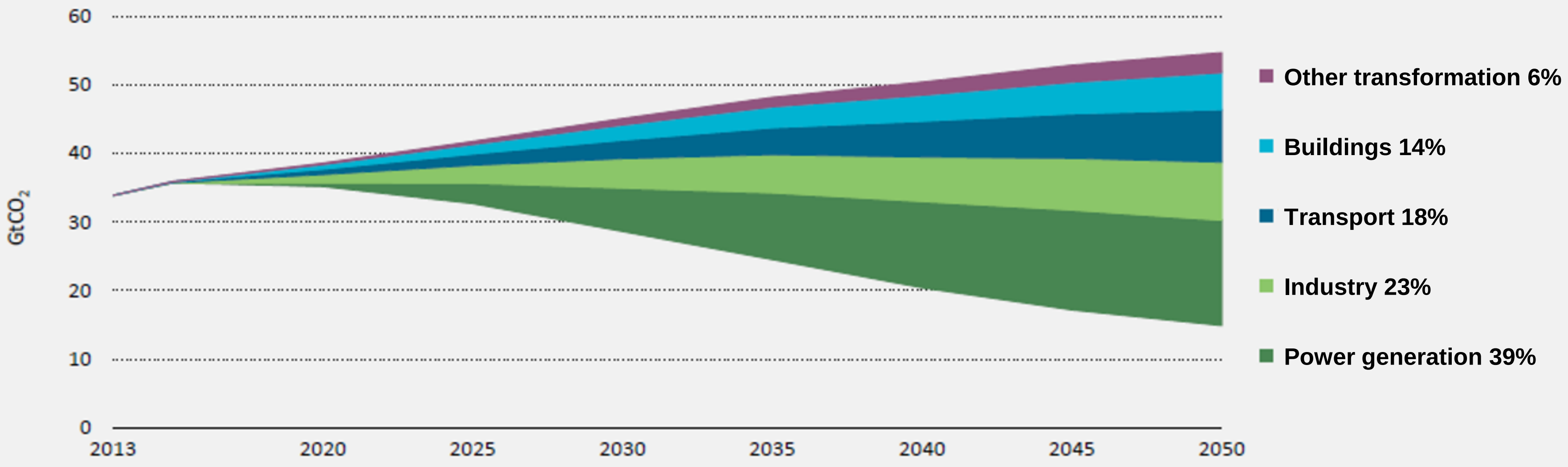
6DS	▪ **Almost 65% growth** in primary energy supply compared to that of 2013 ▪ **Fossil fuels : almost 77%** of energy provided
4DS	▪ **Almost 50% growth** in primary energy supply compared to that of 2013 ▪ **Fossil fuels : still almost 70%** of energy provided
2DS	▪ **Almost 16% growth** in primary energy supply compared to that of 2013 ▪ **Fossil fuels : almost 45%** of energy provided

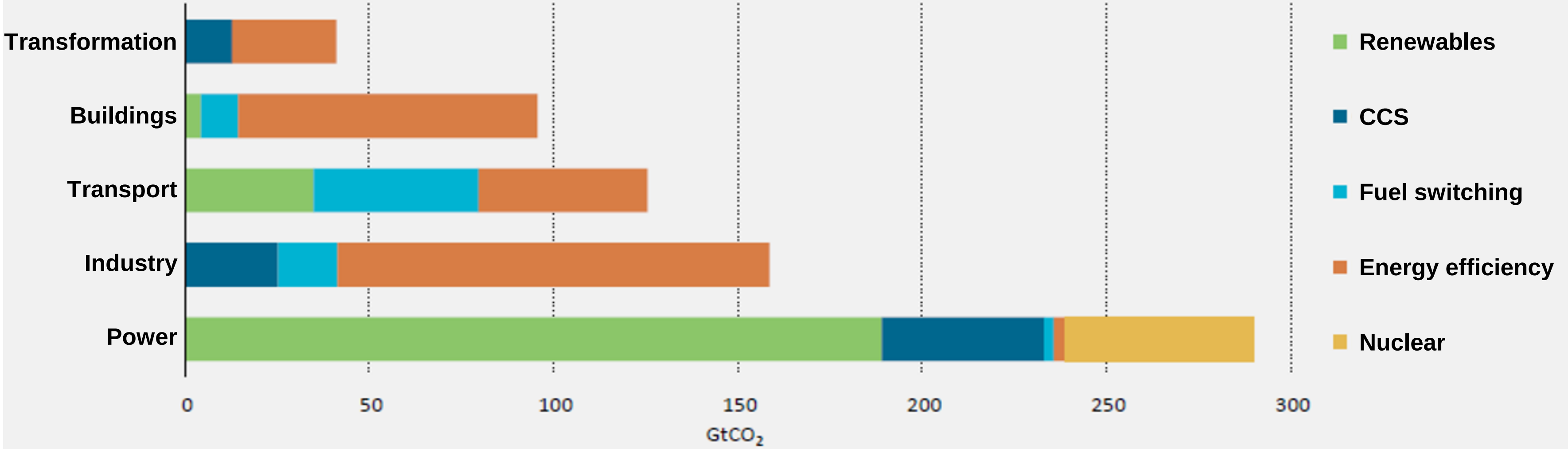
Contributions of Technologies to CO_2 Reductions



Source : ETP 2016, IEA

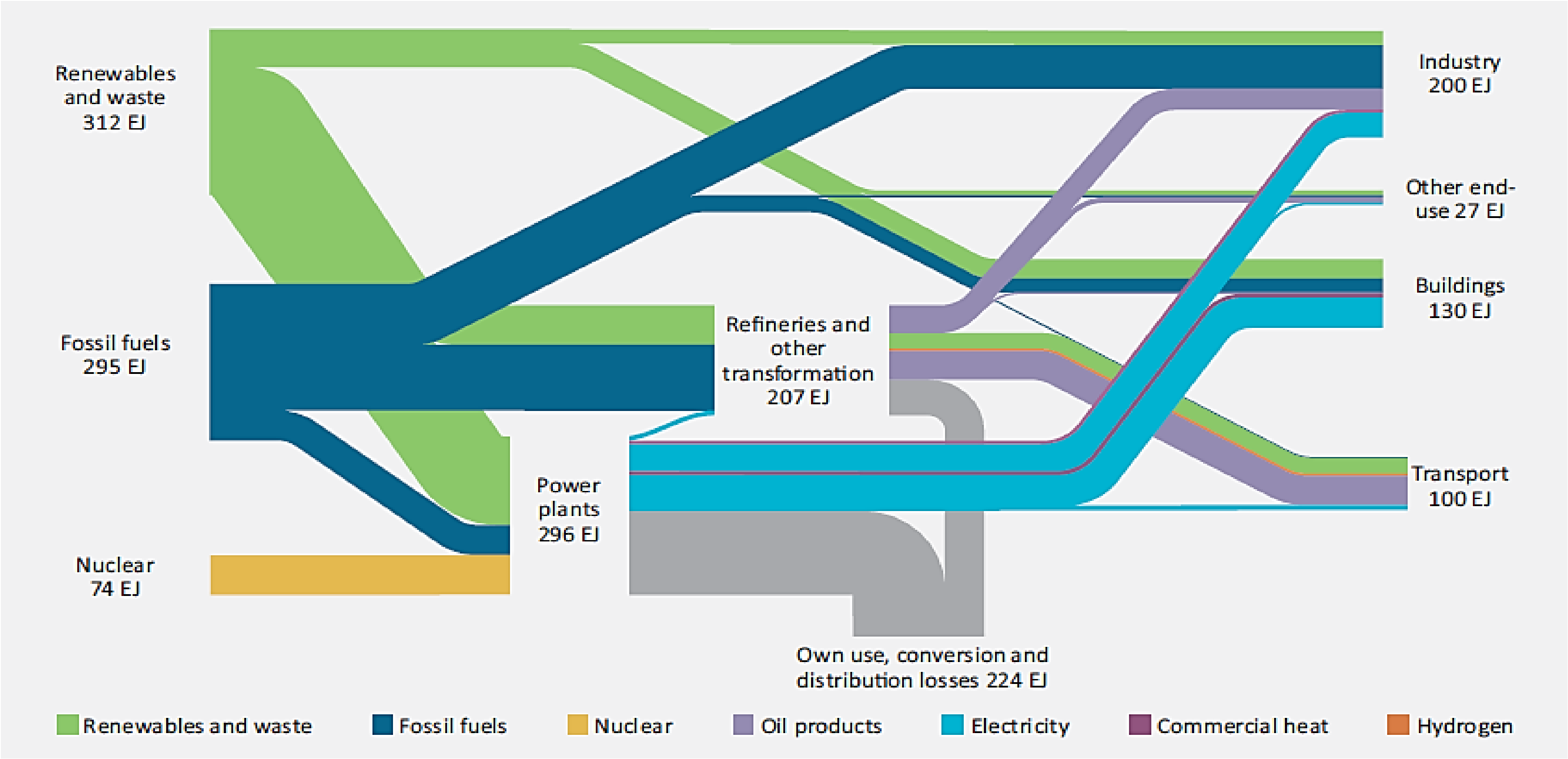
Global CO_2 Reductions between 6DS and 2DS by Sector and Technology





Source : ETP 2016, IEA

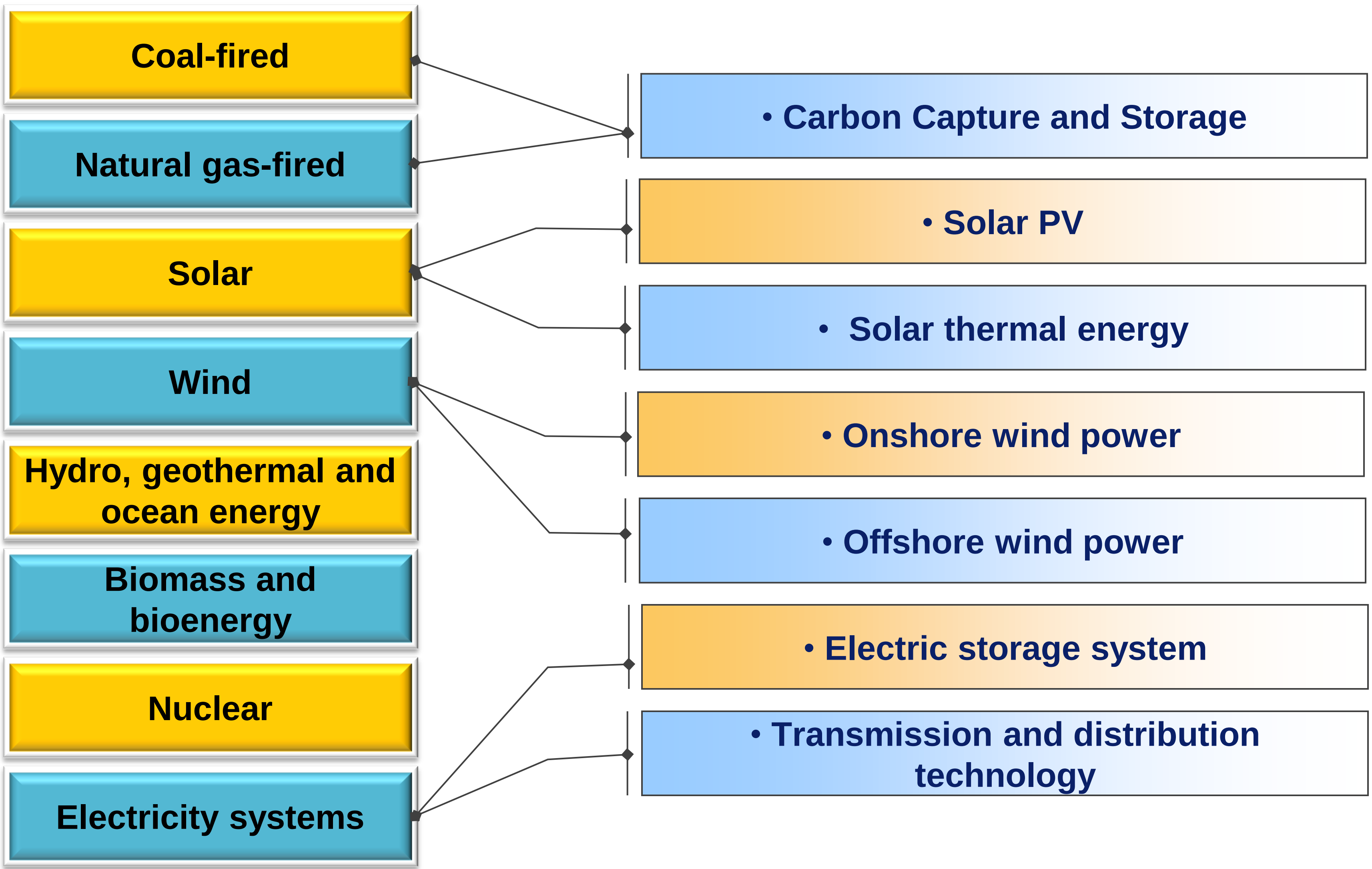
Transformed Energy System in 2DS in 2050



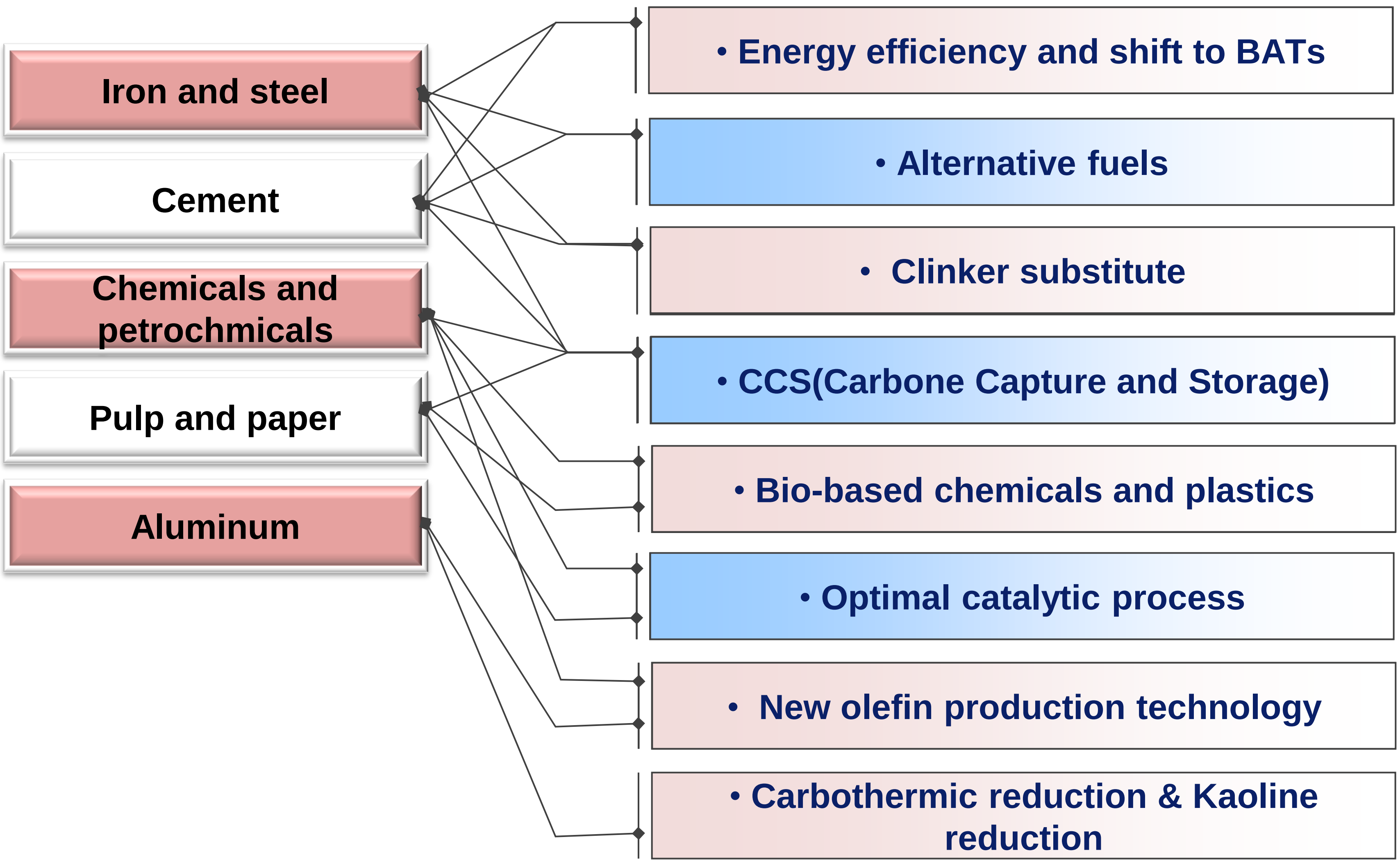
Source : ETP 2014, IEA

- Despite decreased fossil fuel use by 2050 in 2DS, it remains an important role (over 40%), particularly for direct use in industry, transport, and power sector.
- Increased dependence on CCS, renewables, and nuclear to long-term climate goals

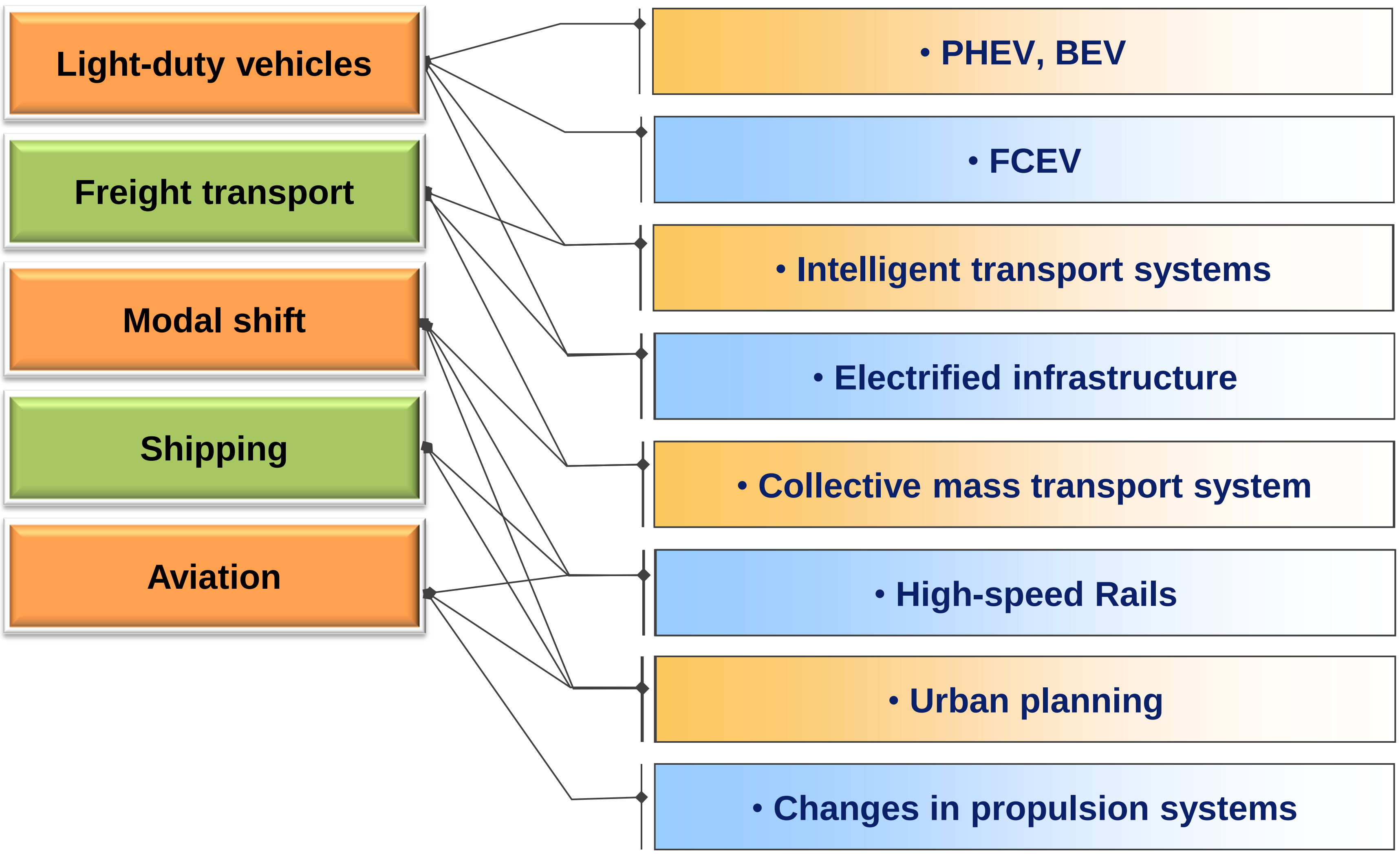
Technology Roadmap
– Power Generation



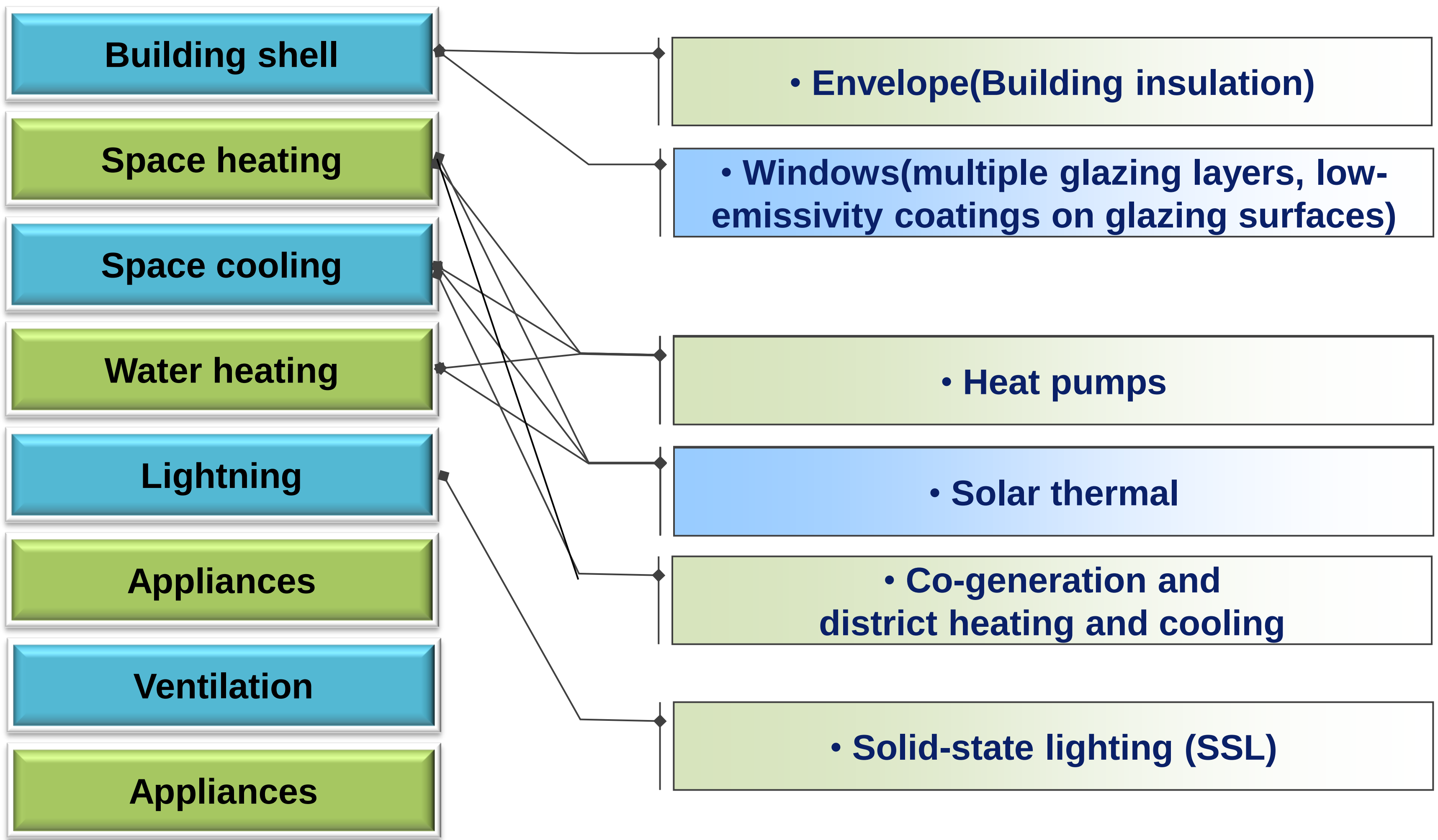
Technology Roadmap
– Industry



Technology Roadmap
– Transport



Technology Roadmap
– Building

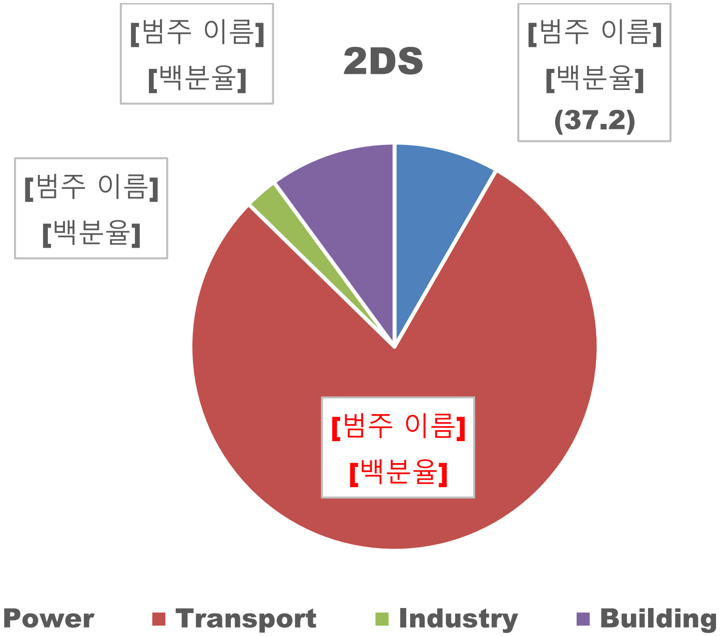


Investment Needs

- **6DS scenario**
  - Total cumulative investment needs in the 6DS scenario are estimated to be USD 434.3 trillion between 2016 and 2050
- **2DS scenario**
  - USD 446.9 trillion (additional USD 12.6 trillion compared to 6DS scenario)
  - Average annual investment is USD 12.8 trillion (USD 12.4 trillion for the 6DS)

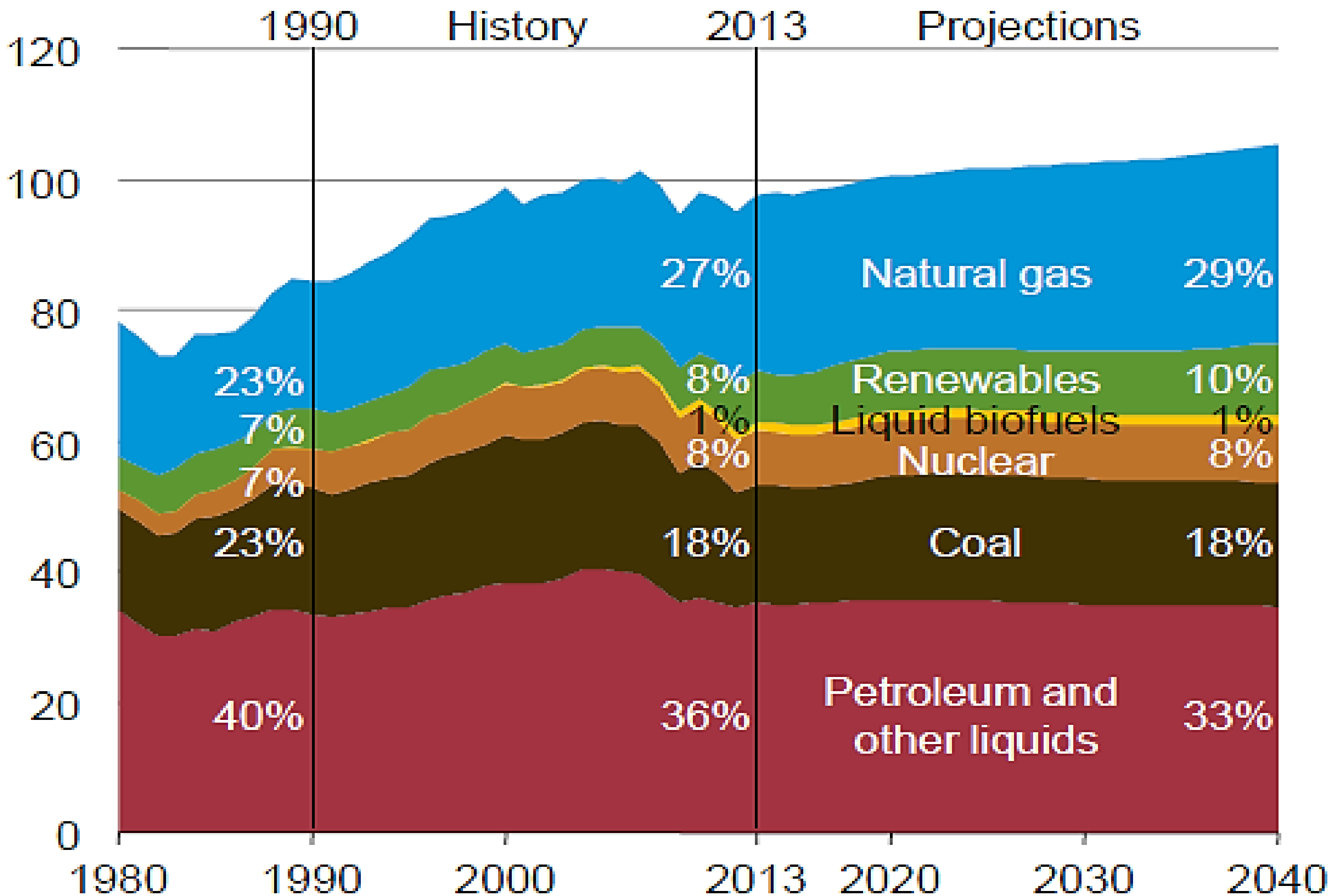
Investment requirements by sector, 2016-2050

(USD trillion)



Source : ETP 2016, IEA

Perspectives of Energy Resources

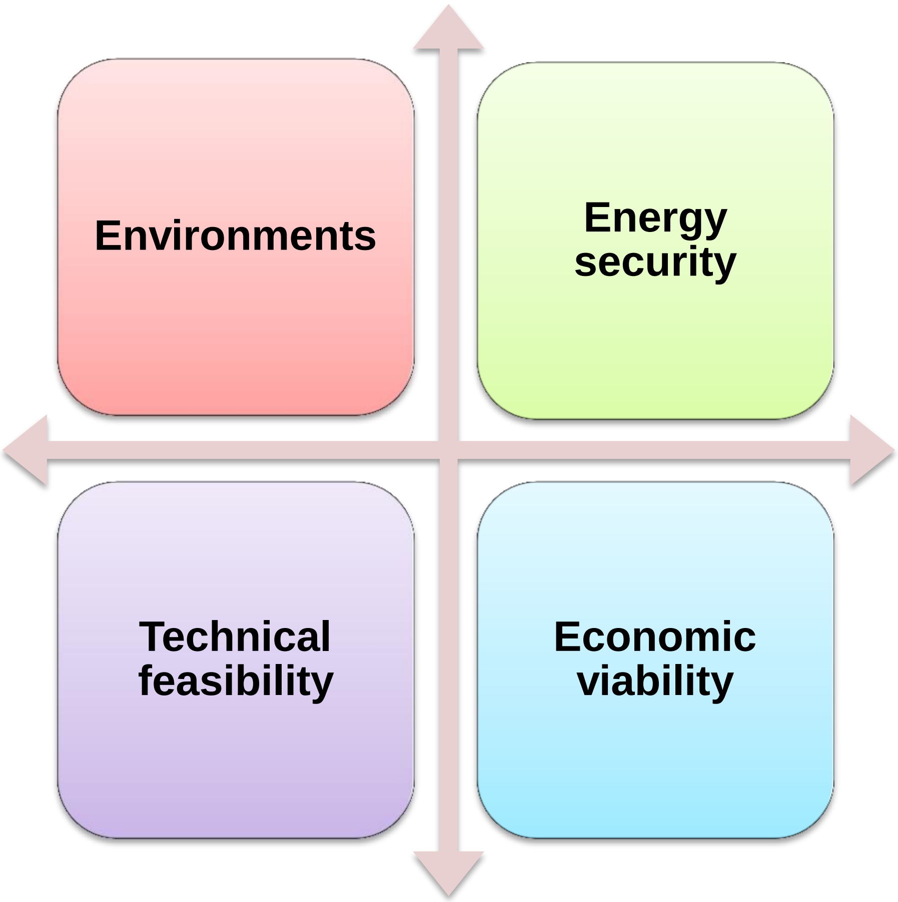


Annual Energy Outlook, EIA, 2015

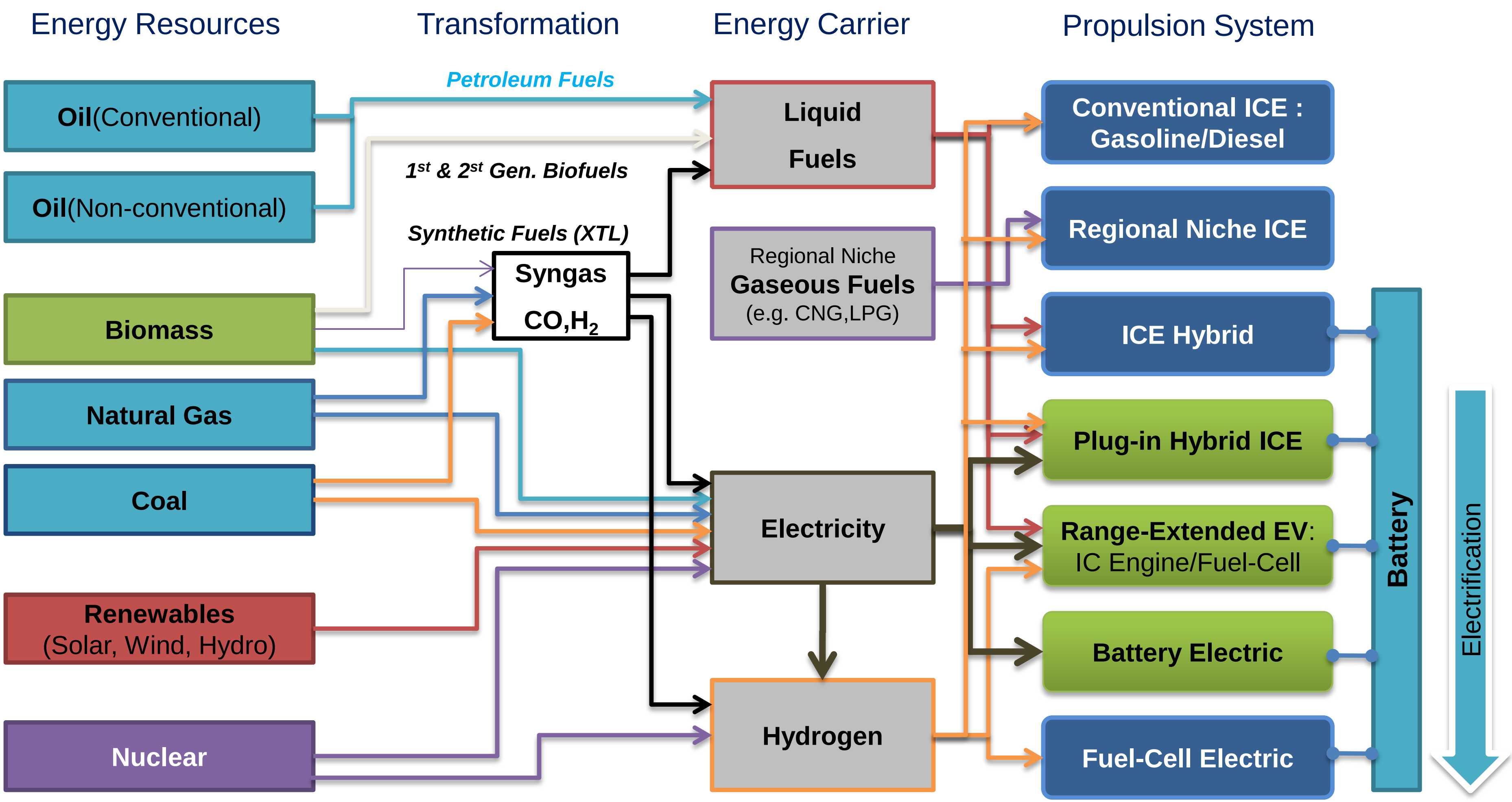
Strategies of Energy Technology Development

Considerations : Benefits, Balances, Priorities

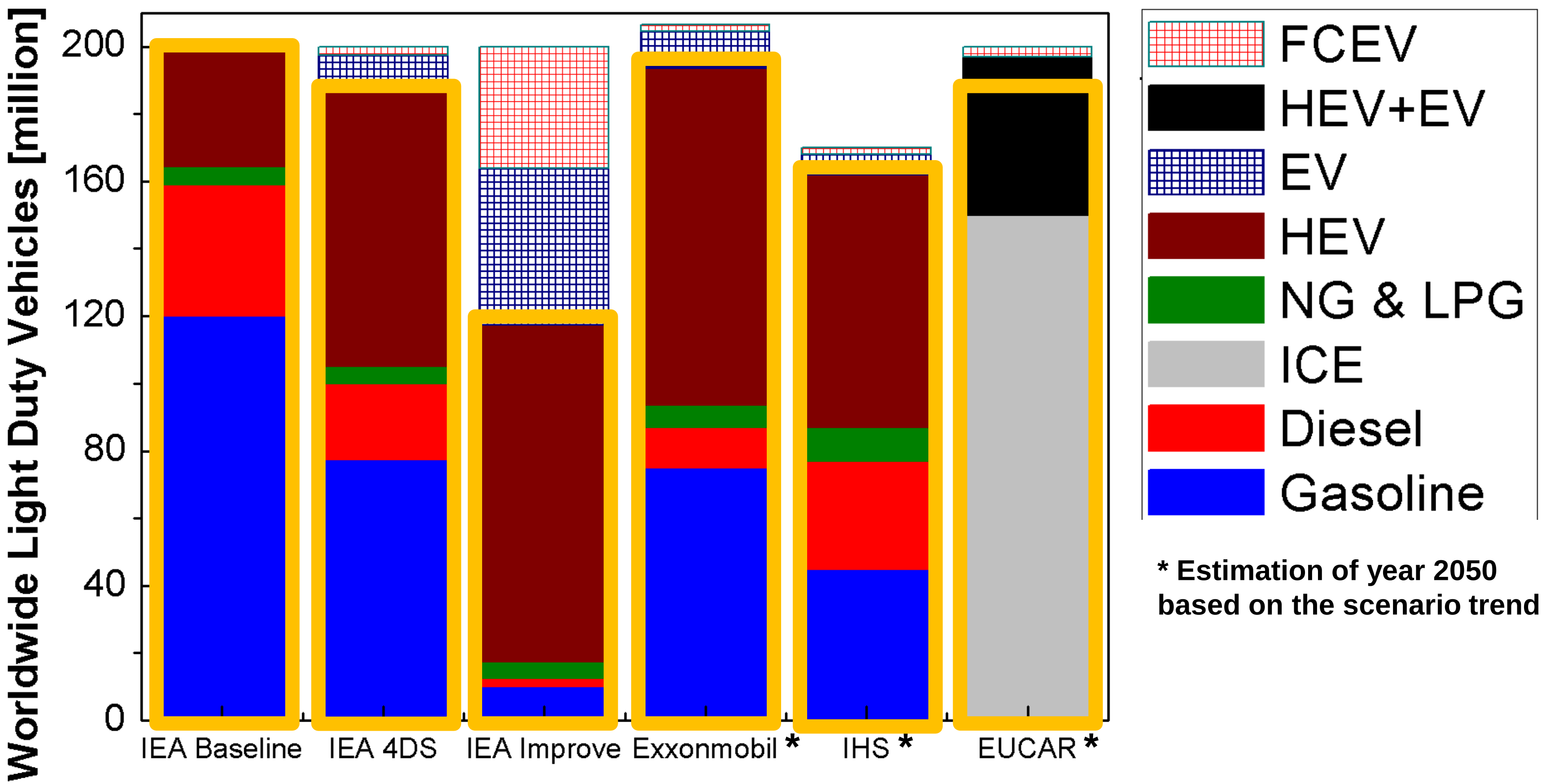
→ Feasible Sustainability



Case of Transportation
– Challenges in Transport Sector



Case of Transportation
– 2050 Global Light-Duty Vehicle Perspectives



* Estimation of year 2050 based on the scenario trend

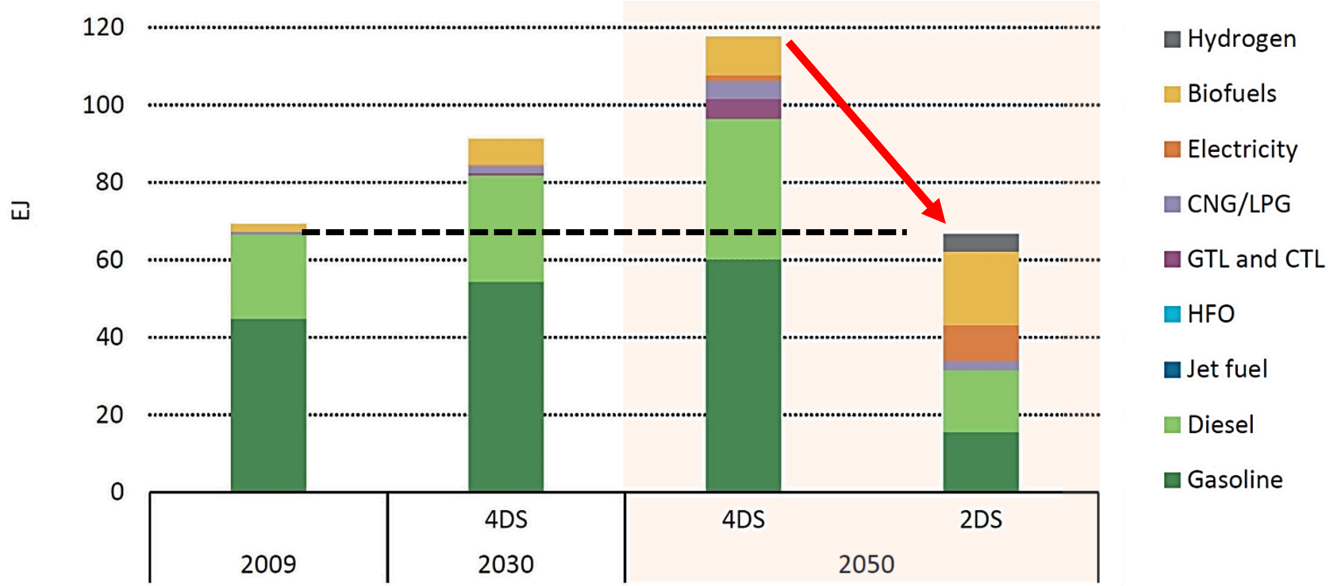
➢ FCEV, EV, HEVs are expected to increase only in the extreme case (IEA Improve); however, the domination of the efficient internal combustion engine (> 70%) + alternative fuels and hybridization are expected to be major driving forces in reality (EUCAR, Exxonmobil etc.)

Case of Transportation
– Scenarios: Vision for Fuel

- In the 2DS (an ideal IEA ETP2050 scenario), energy use and fuel mix in ground transportation need to change dramatically to meet the targeted CO_2 emission cuts.

- By 2050, global energy demand returns to 2009 levels, and is more diversified due to higher shares of low-carbon fuels.
  - Electricity / biofuels / hydrogen (fuel cell)

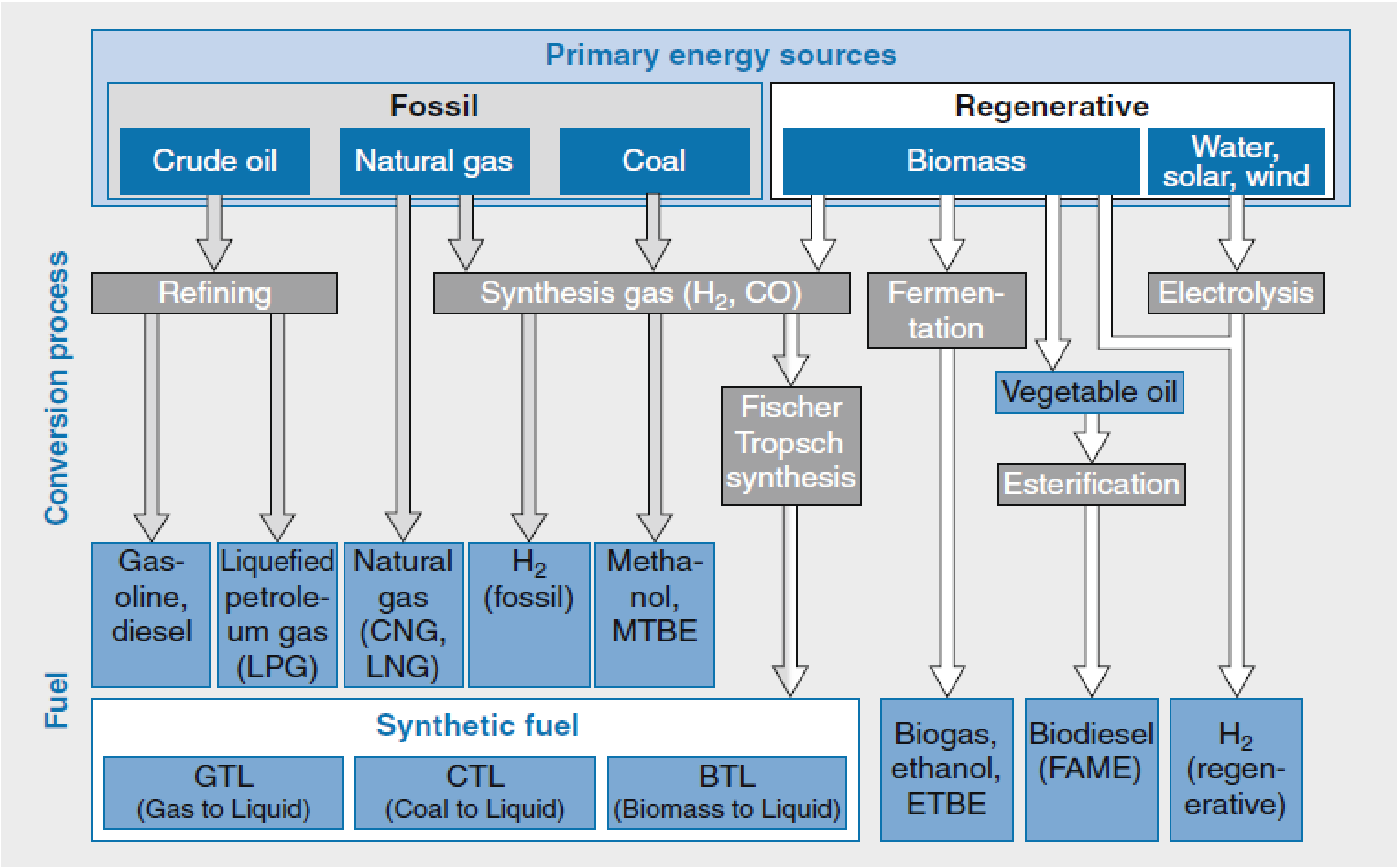
Comparison of fuel demand by fuel type



Source: ETP 2050, IEA 2012

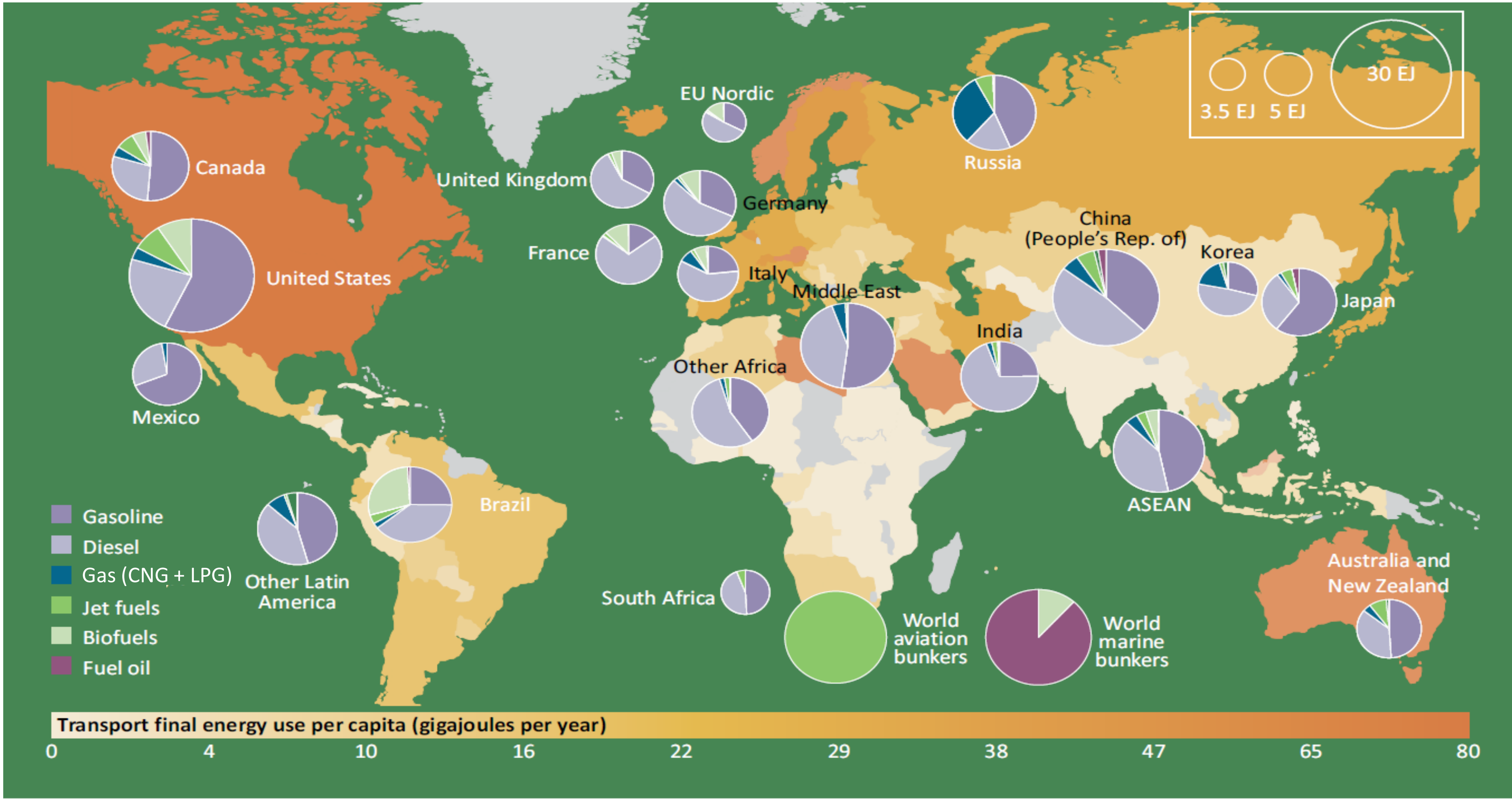
Case of Transportation
– Fuel production pathways

Source: K. Reif. Gasoline engine management, Springer 2015



Case of Transportation
– Current transport energy use (conventional + renewable)

Transport energy use, total and per capita, 2013



Source: Energy Technology Perspectives 2016

- Substantial amount of biofuels in specific area (Brazil, North America, Europe)
- Substantial amount of other fuels (such as CNG & LPG) in Korea, Russia, China

Contents

- Energy Technology Perspectives (ETP) 2050 Scenario
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  - Case of Transportation
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  - **Improvement in Engine Combustion**
  - **Fuel-Cell Technology**
  - **Thin Films for Solar Cell**
  - **Novel Energy Harvesting System**
  - **Thermophotovoltaic (TPV) System**
  - **Vacuum Insulation**

Improvement in Engine Combustion – Biodiesel; Direct Combustion Images

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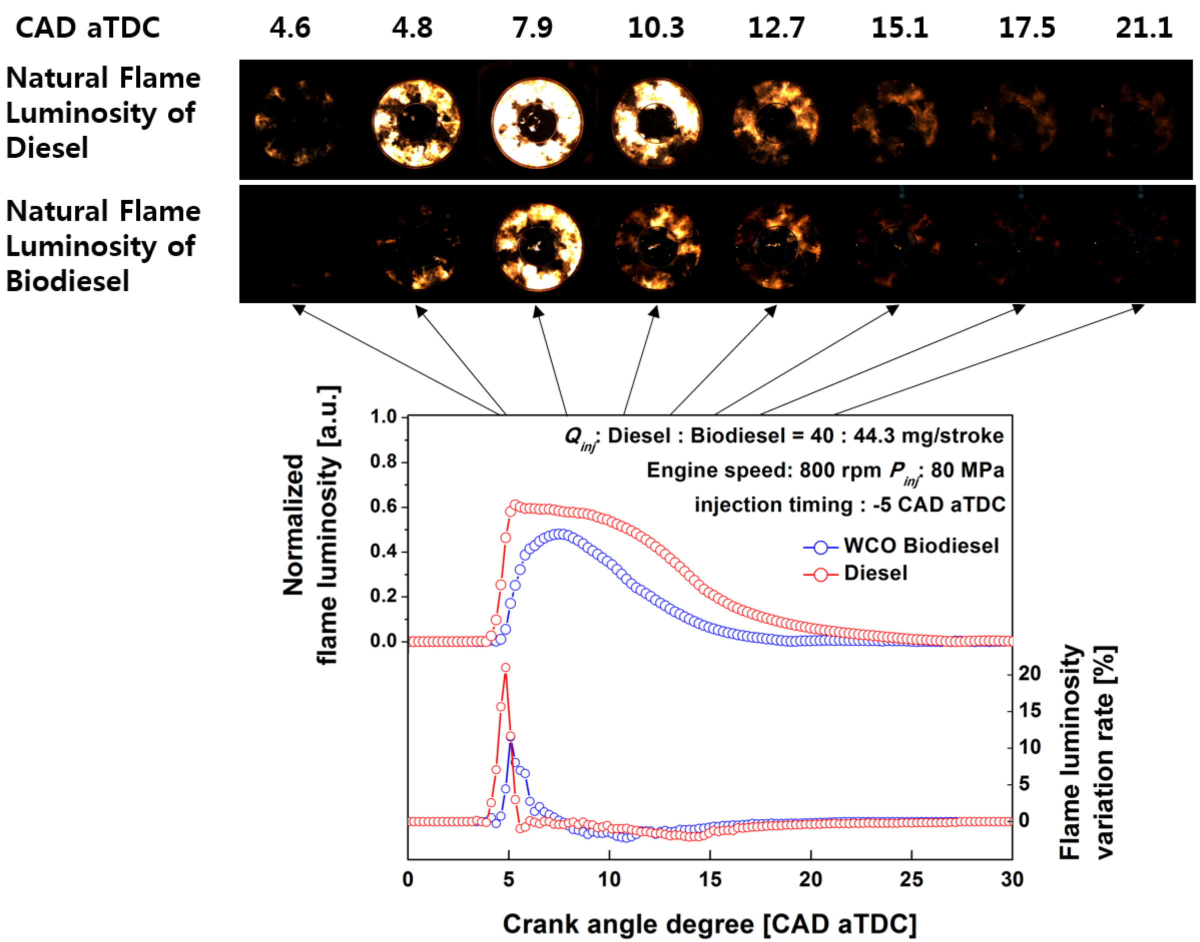
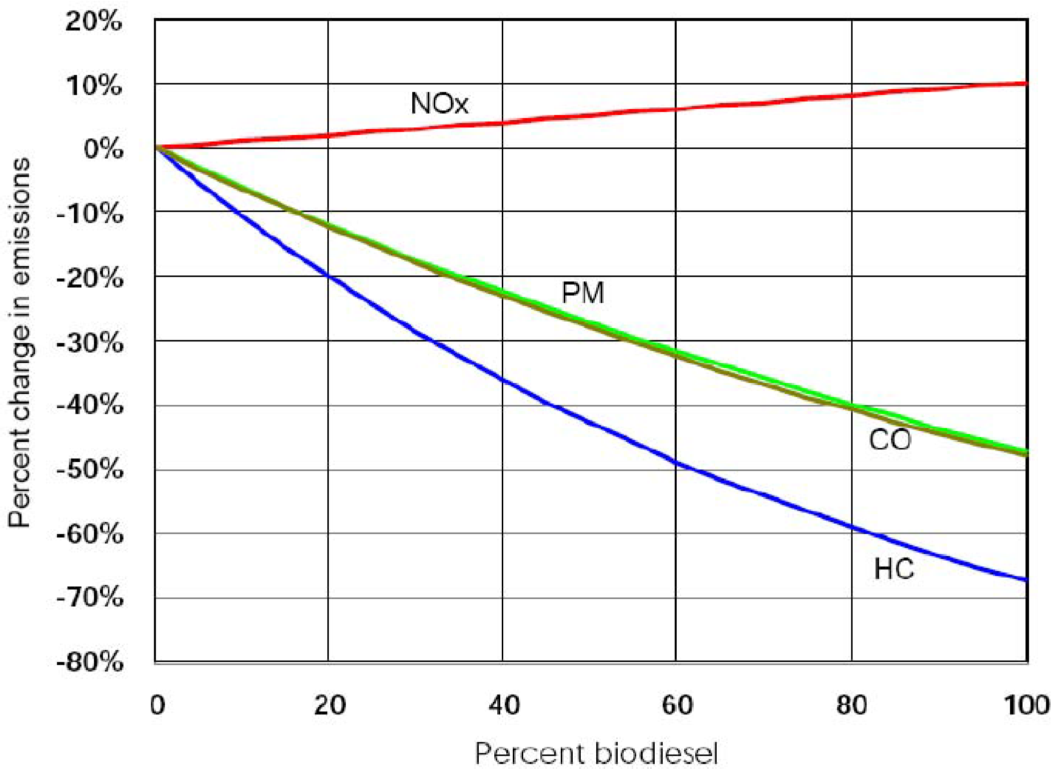
Prof. Choongsik Bae

T_{inj} = -5 CAD ATDC, pinj = 80 MPa



Biodiesel – Direct combustion images

Average emission impacts of biodiesel fuels in compression ignition engines



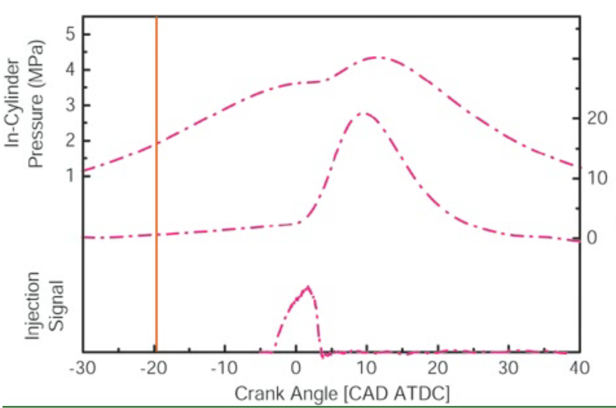
- It is generally accepted that, the use of oxygenated fuel such as biodiesel yields reduction of PM, CO, and HC emission due to the presence of oxygen atom.
- However, the NOx emission tends to increase.

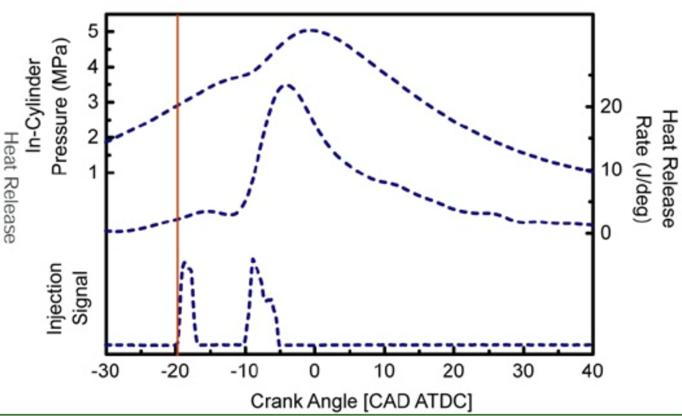
Source: United States Environmental Protection Agency (EPA), Comprehensive analysis of biodiesel impacts on exhaust emissions, (2002) EPA420-02-001.

Improvement in Engine Combustion
– DME; Combustion Visualization in Engines

DME

Diesel





<u>Expected benefits of DME combustion</u>

- ✓ Rapid vaporization
- ✓ Shorter burn duration (→ different injection control scheme)
- ✓ Less smoke

Fuel-Cell Technology
– Application of Diesel Reformer and Fuel-Cell

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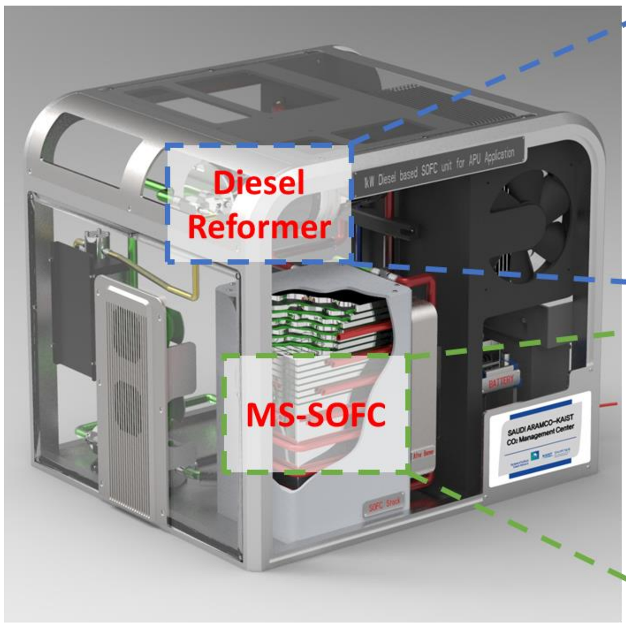
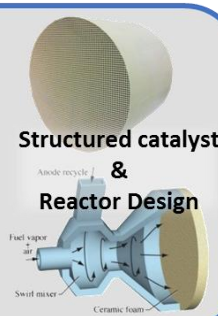
- **Auxiliary Power Unit (APU) at Heavy Duty Vehicles**
  - ✓ A sub-power system for electronics and air conditioning
  - ✓ Diesel reformer : Conversion of diesel into hydrogen
  - ✓ Solid Oxide Fuel Cell : Highly efficient electricity generation

Integrated APU system



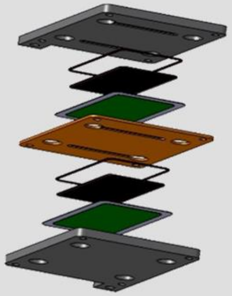
Diesel Reformer

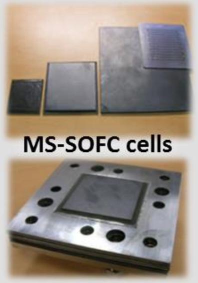
- **Durable** hydrogen production with <u>structured catalyst application</u>
- **Thermally independent** design



Metal-supported SOFC

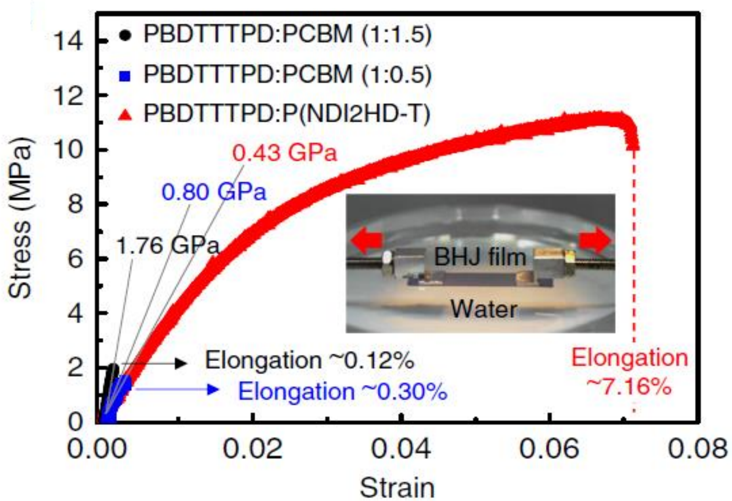
- High **mechanical strength** with <u>metal-based interconnect</u>
- **Highly efficient** electrical power

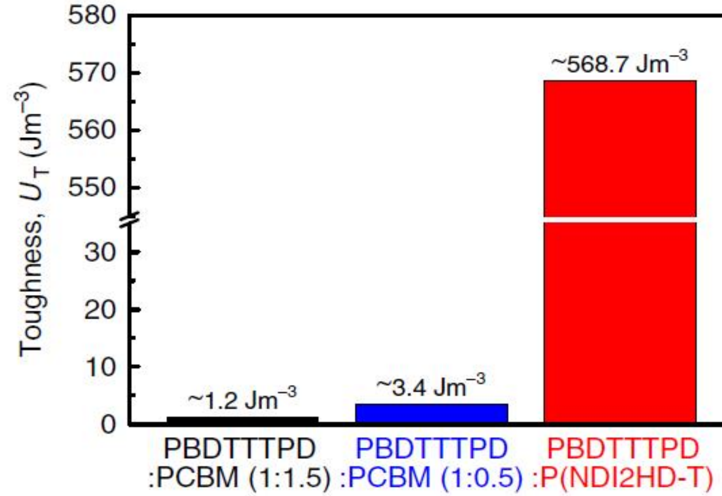


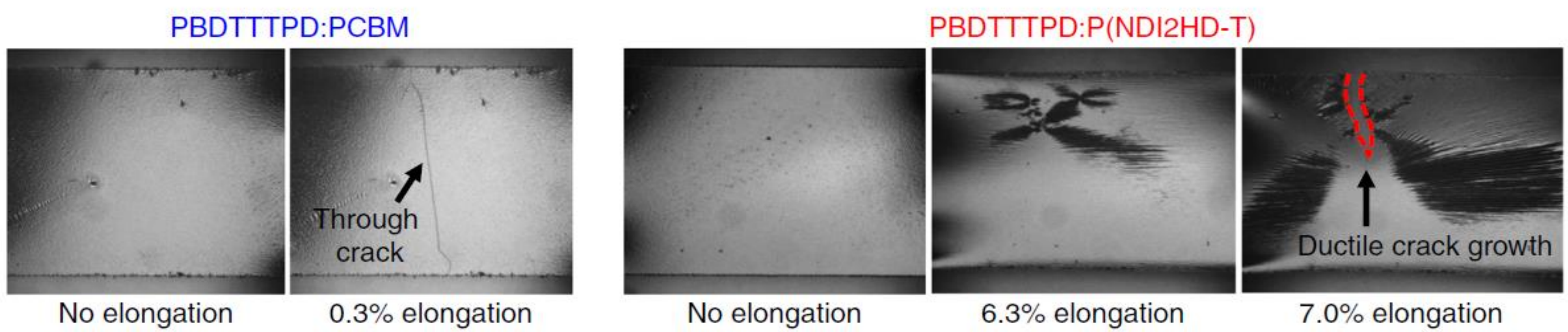


Thin Films for Solar Cell
– All Polymer Solar Cells

High power-conversion efficiency of 6.64% (6.12% for PCBM) with 60-fold improvement in elongation at break.



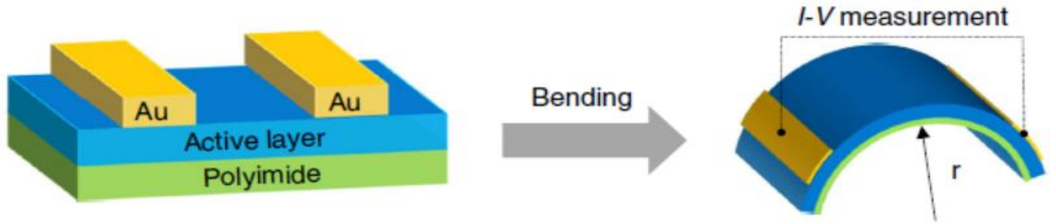


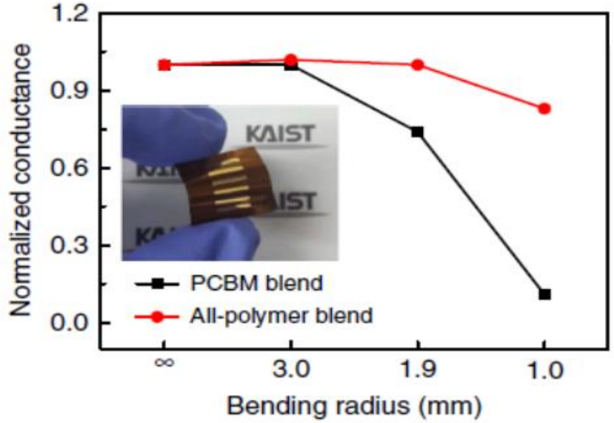


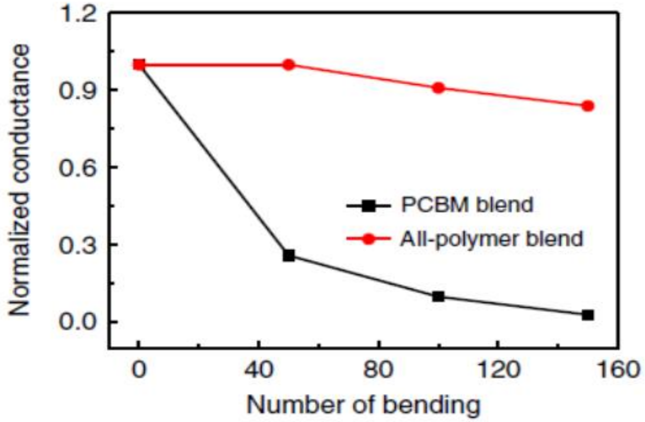
T. Kim, J.-H. Kim, T. E. Kang, C. Lee, H. Kang, M. Shin, C. Wang, B. Ma, U. Jeong, T.-S. Kim*, and B. J. Kim*, "Flexible, Highly Efficient All-Polymer Solar Cells", ***Nature Communications***, 6, 8547, 2015.

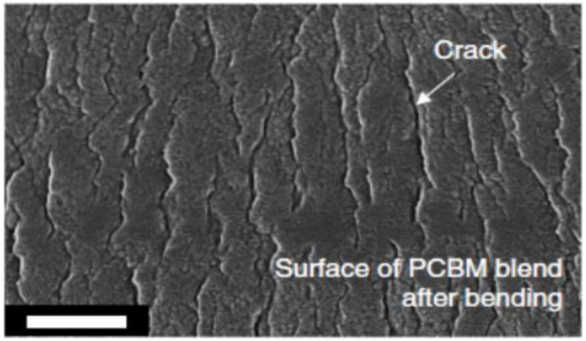
Thin Films for Solar Cell
– All Polymer Solar Cells

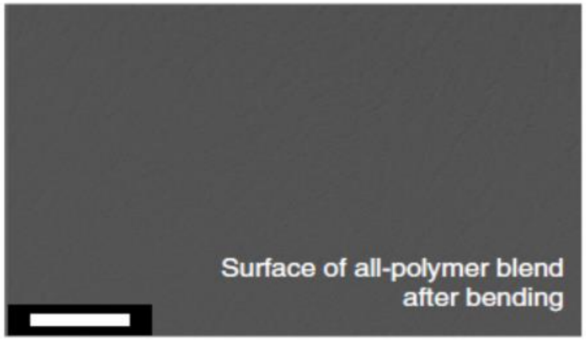
Prof. Taeksoo Kim











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Novel Energy Harvesting System

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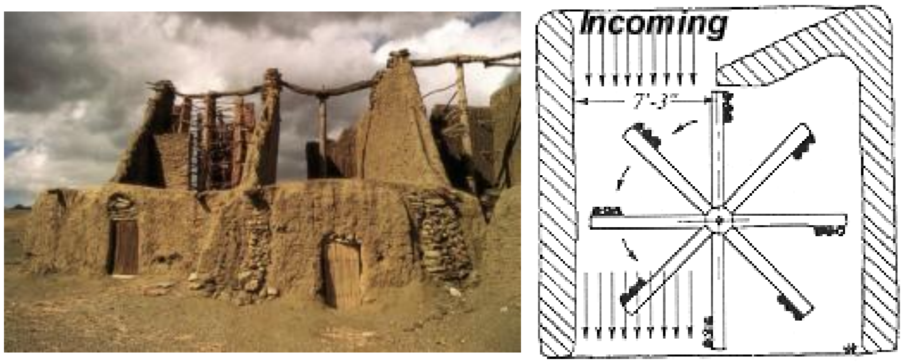
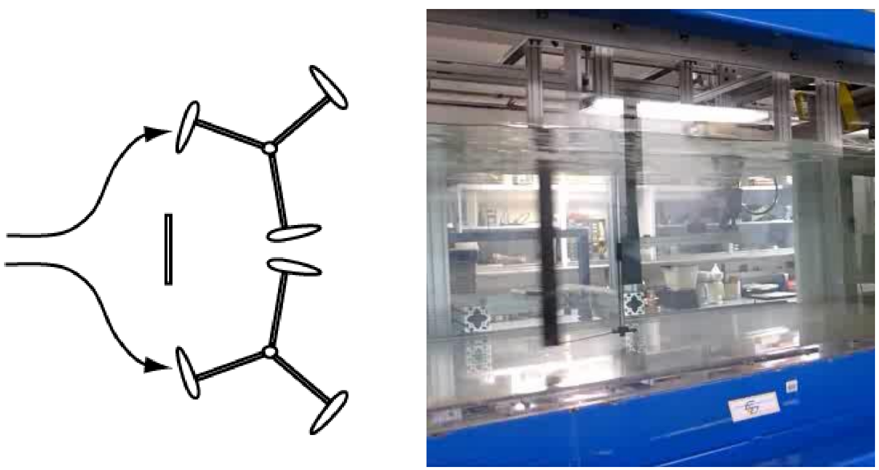
Prof. Daegyoum Kim

Rotary turbine with an upstream structure

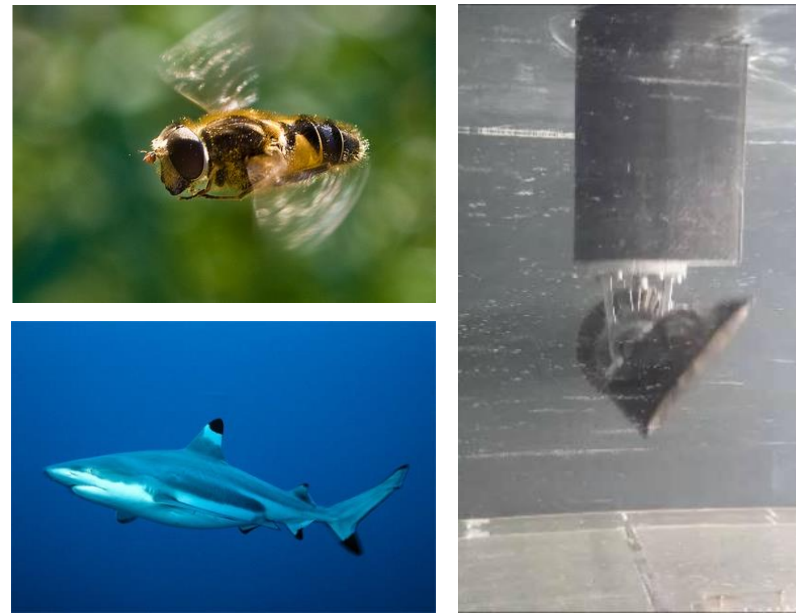


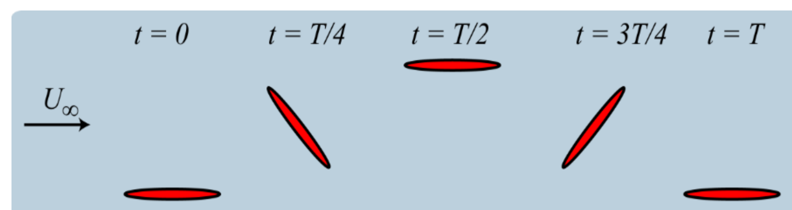
Ancient Persian windmill



Vertical-axis turbine with an upstream deflector
(*J. Wind Eng. Ind. Aerod.* 2013, *Exp. Fluids* 2014)

Bio-inspired energy harvesting system





A pitching and heaving hydrofoil

Novel Energy Harvesting System

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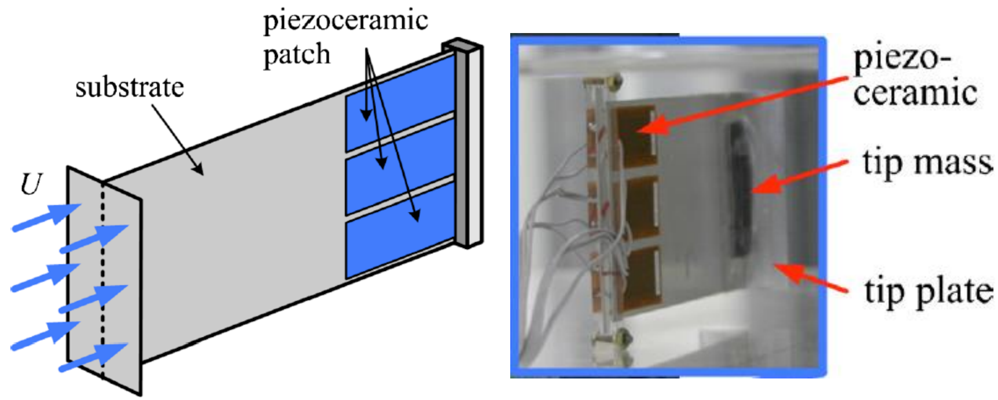
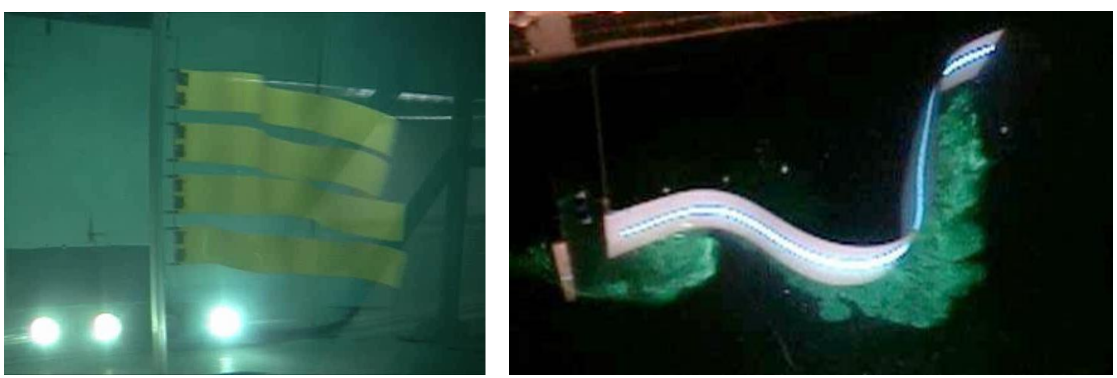
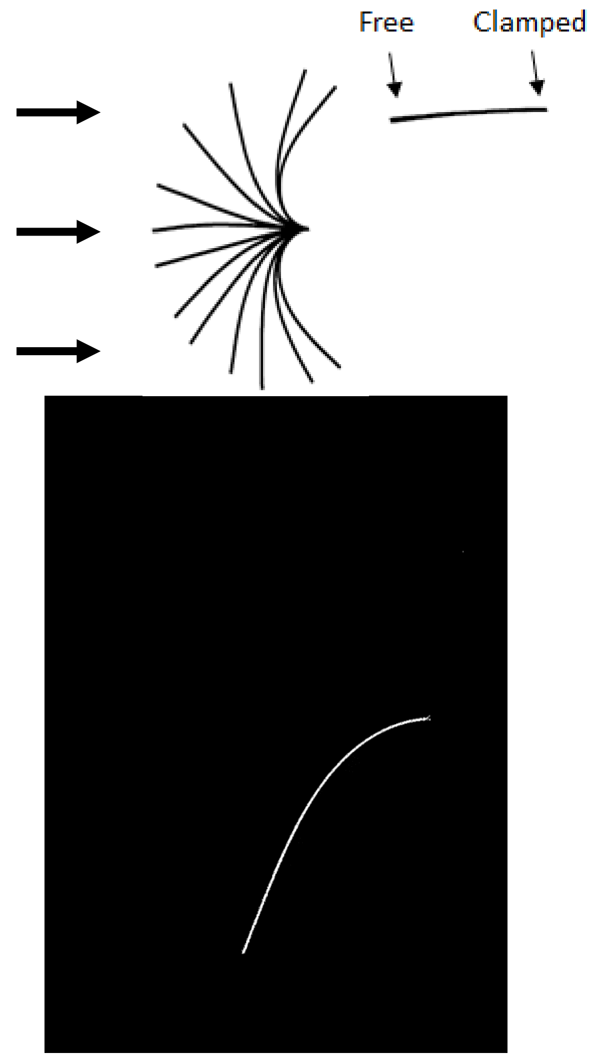
Energy harvesting from flutter



T-shaped cantilever
(Kwon, *Appl. Phys. Lett.*, 2010)



Membrane behind a bluff body
(Allen and Smits, *J. Fluid Struct*, 2001)



Flapping inverted flag
(*J Fluid Mech*, 2013; *J Fluid Mech*, 2016)

Thermophotovoltaic (TPV) system

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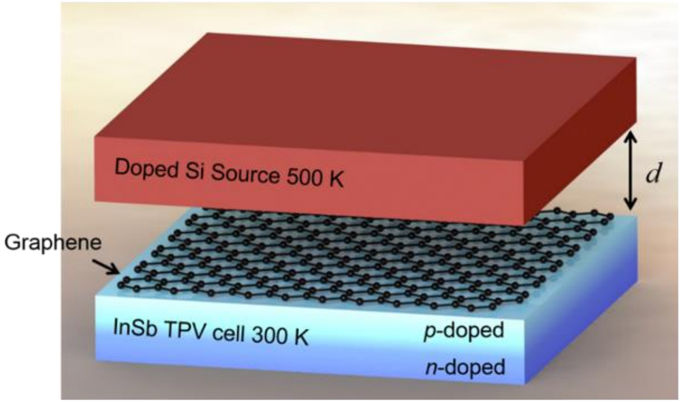
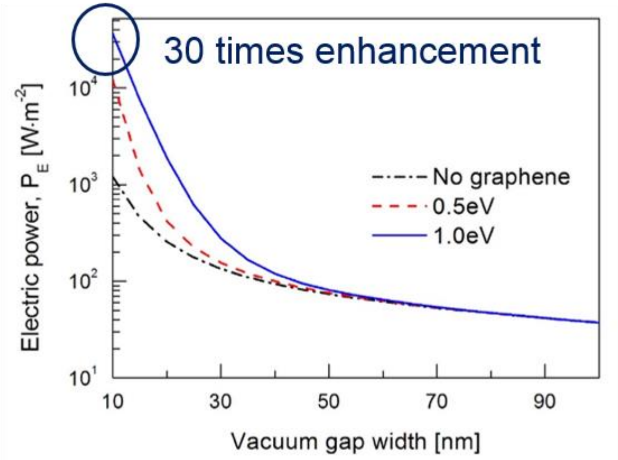
Prof. Bongjae Lee

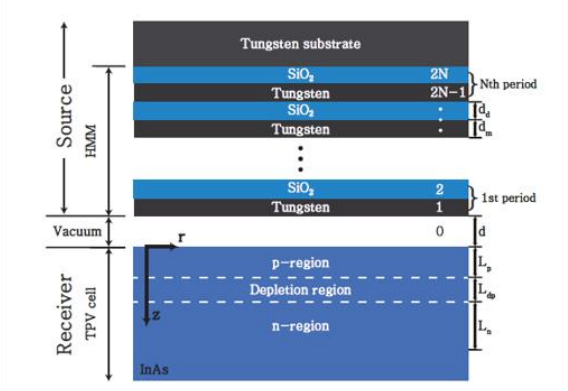
- Graphene-assisted near-field TPV system

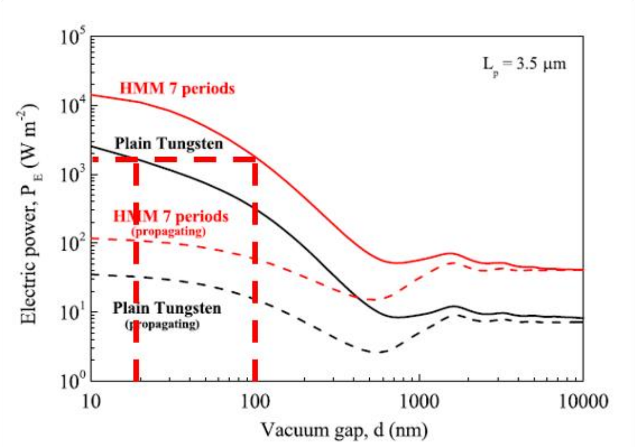




M. Lim *et al.*, *Opt. Express* **23**, A240–253 (2015)

- Hyperbolic metamaterial-based near-field TPV system

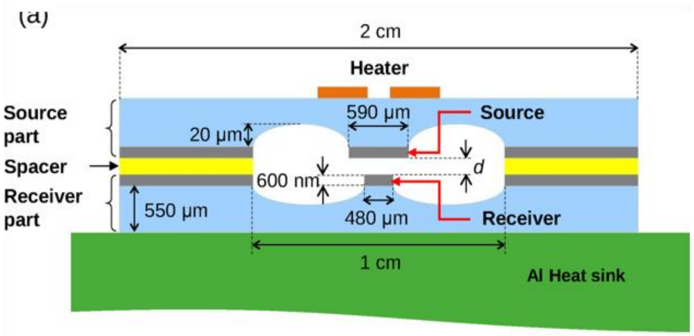


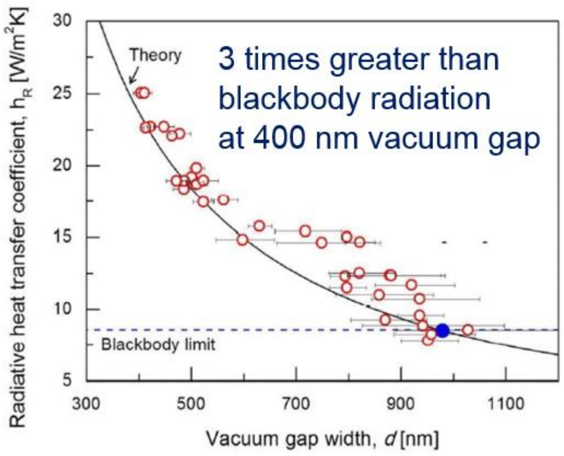


S. Jin *et al.*, *Opt. Express* **24**, A635–649 (2016)

Thermophotovoltaic (TPV) system

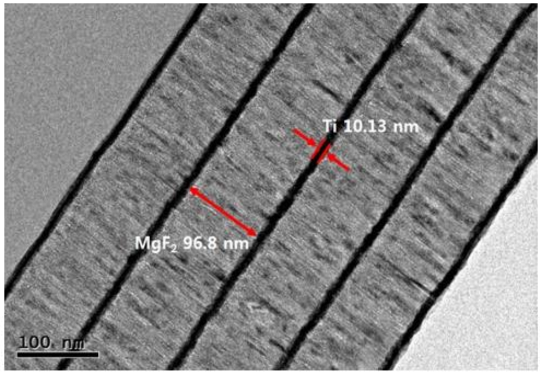
- Demonstration of near-field thermal radiation between plates

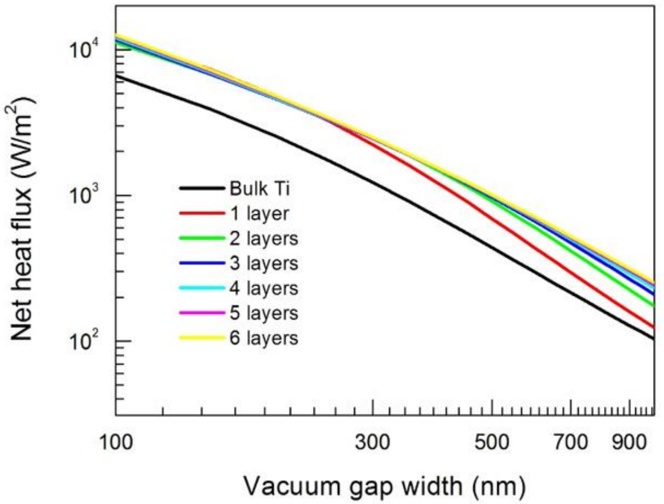




M. Lim *et al.*, *Phys. Rev. B* **91**, 195136 (2015)

- Demonstration of near-field thermal radiation between hyperbolic-metamaterials





Vacuum Insulation

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Prof. Taeho Song

- **Vacuum insulation saves energy and space! Use for,**
  - New and existing buildings ; 70% energy saving with less than 10% thickness.
  - Refrigerator; 50% electricity saving possible .
  - LNG; LNG-carrier(current boil-off rate is about 0.1%/day with 50cm-thickness; boil-off rate and volume saving 50%, for more than 50 yrs), LNG-fuel tank, etc.
  - Automobiles; wind-shield/roof/refrigerator/coolant tank/electric vehicle climate control, etc.
  - DNA chips, organ transportation, clothes, etc, etc.

Vacuum Insulation

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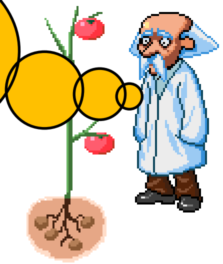
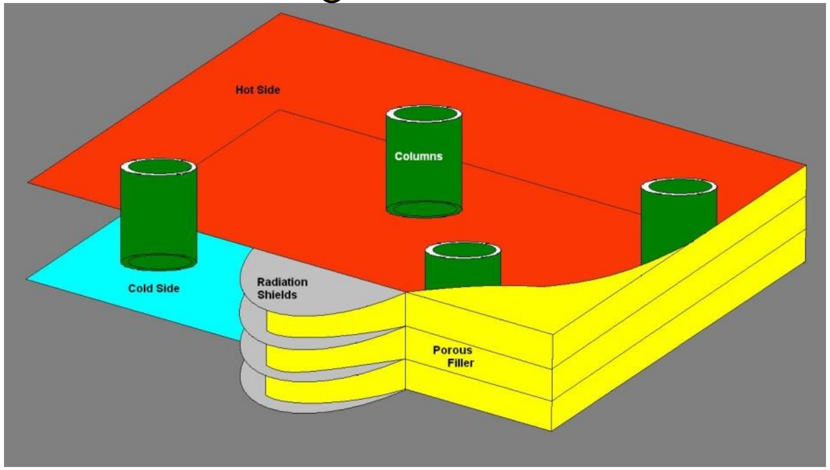
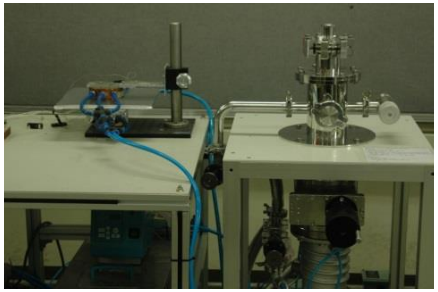
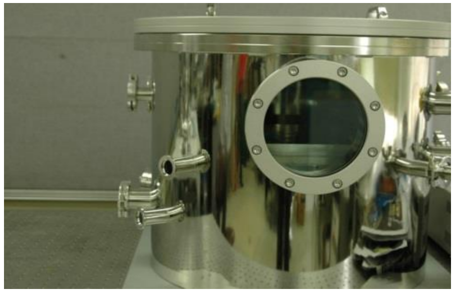
k reached 0.0009 W/m-K (WR of 2013).

We are leading the research worldwide. Also, a few start-up companies are being run by the alumni!









Summary

- Three scenarios (6DS, 4DS, 2DS) have been considered in IEA ETP 2050; Ambitious 2DS is too idealistic, while 6DS is realistic.
- Four parameters (environments, energy security, technical feasibility, economic viability) should be considered for energy technology development.
- Scientific approach for the mix of economical conventional energy and innovative renewable energy is needed in energy systems for a while.
- R&D is needed to secure technological maturity of the implementation of the innovative renewable energy.

Thank you for your kind attention

Prof. Choongsik Bae

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