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The development effort required to accelerate vessel deployment of zero carbon fuels

Mark Parrett, November 2019

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The material in this presentation is a high level overview of the anticipated R&D effort to determine which zero carbon energy solutions are suitable for future transoceanic shipping, considering only on vessel aspects. It was presented by Ricardo's Technology Strategy consulting team at the Environmental Defense Fund event 'Navigating towards a zero-carbon future' on 8th November 2019 at the IMO, London. The material is intended to provoke discussion and should not be reviewed out of the context in which it was presented. For more information please contact info@ricardo.com.

Introduction:
R&D considerations for decarbonising transoceanic shipping

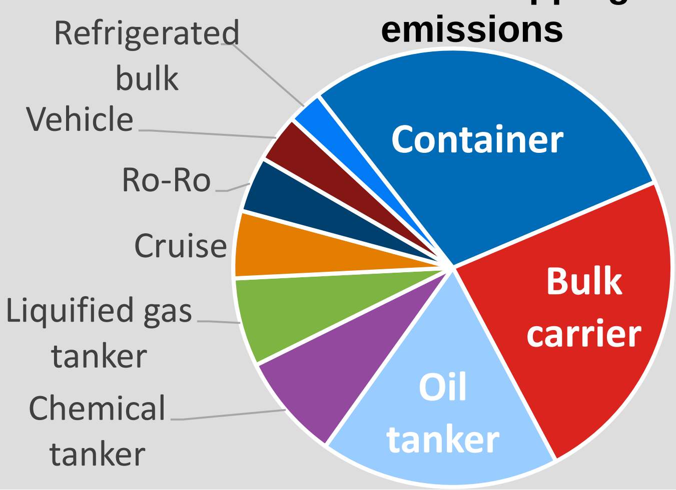
Scope

- ✓ Technology development acceleration
- ✓ Vessel technology
- ✓ Zero carbon energy carriers only

- × Political, commercial, financial aspects
- × Port / bunker infrastructure / technology
- × 'Carbon neutral' energy carriers
- × Zero carbon fuel production

Focus

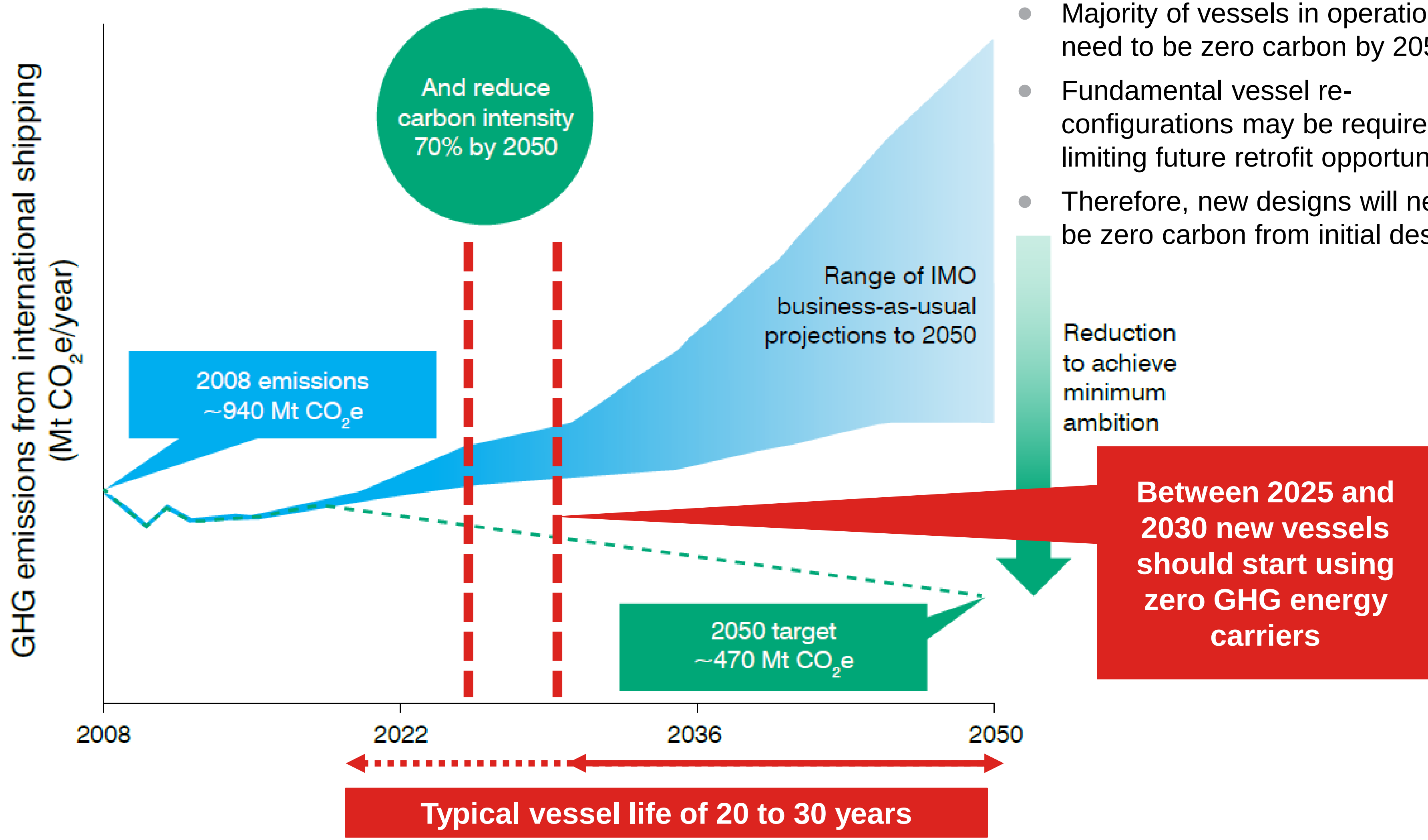
Estimated distribution of transoceanic shipping CO_2 emissions



➔ Transoceanic marine challenge
➔ Focus on container, bulk carrier, tanker

Source: CO_2 emissions (IMO, 2015)

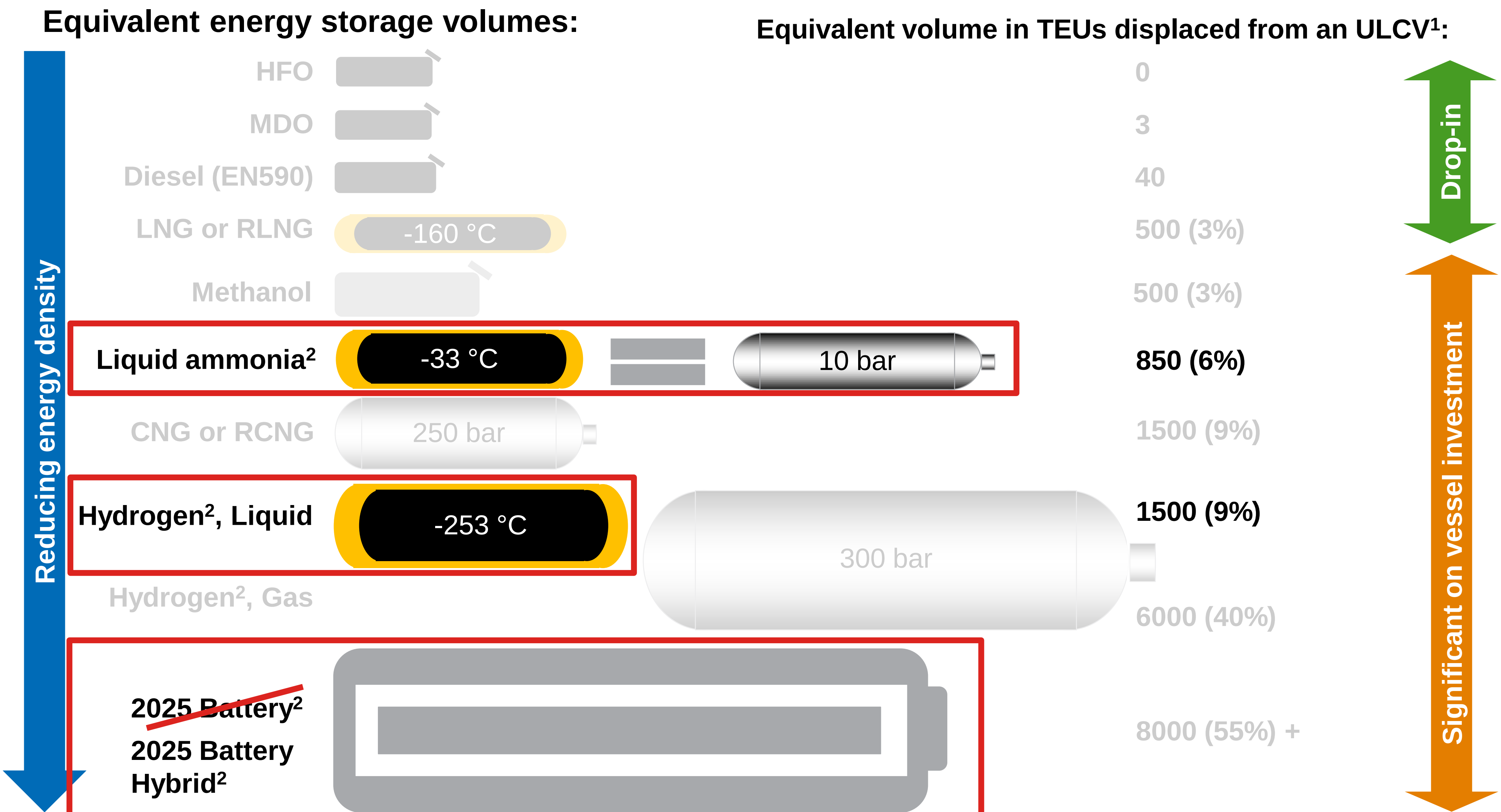
To meet the IMO's 2050 absolute GHG targets will require the first zero carbon fuelled vessels operating in the water between 2025 & 2030



- Majority of vessels in operation will need to be zero carbon by 2050
- Fundamental vessel re-configurations may be required, limiting future retrofit opportunities
- Therefore, new designs will need to be zero carbon from initial design

Source: Sailing on Solar (Ricardo): https://europe.edf.org/news/2019/02/05/shipping-can-reduce-climate-pollution-and-draw-investment-developing-countries

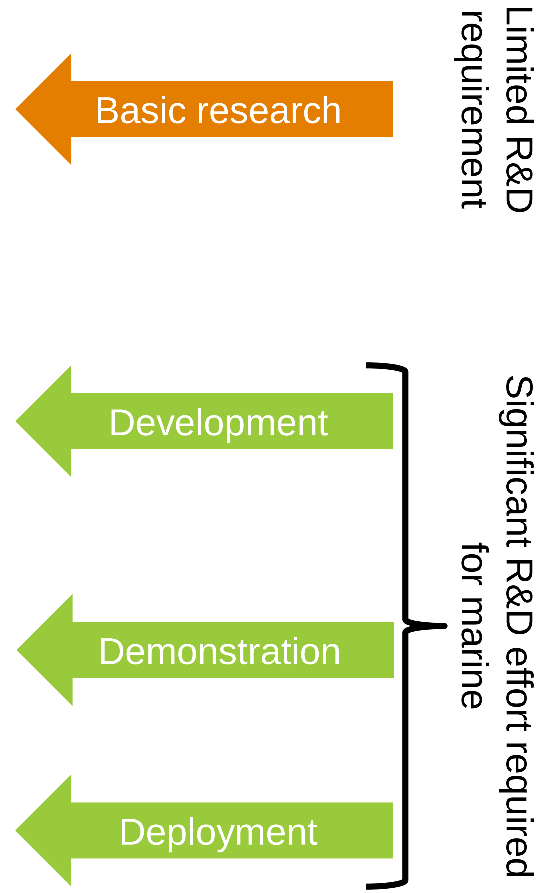
Energy density of lower carbon and zero carbon fuels will likely result in different solutions for different vessel types and sectors



Source: Ricardo analysis based on LHV | [1] ULCV is an Ultra Large Container Vessel and is assumed as 15,000 TEUs | TEU = Twenty-foot Equivalent Unit | [2] Potentially zero carbon

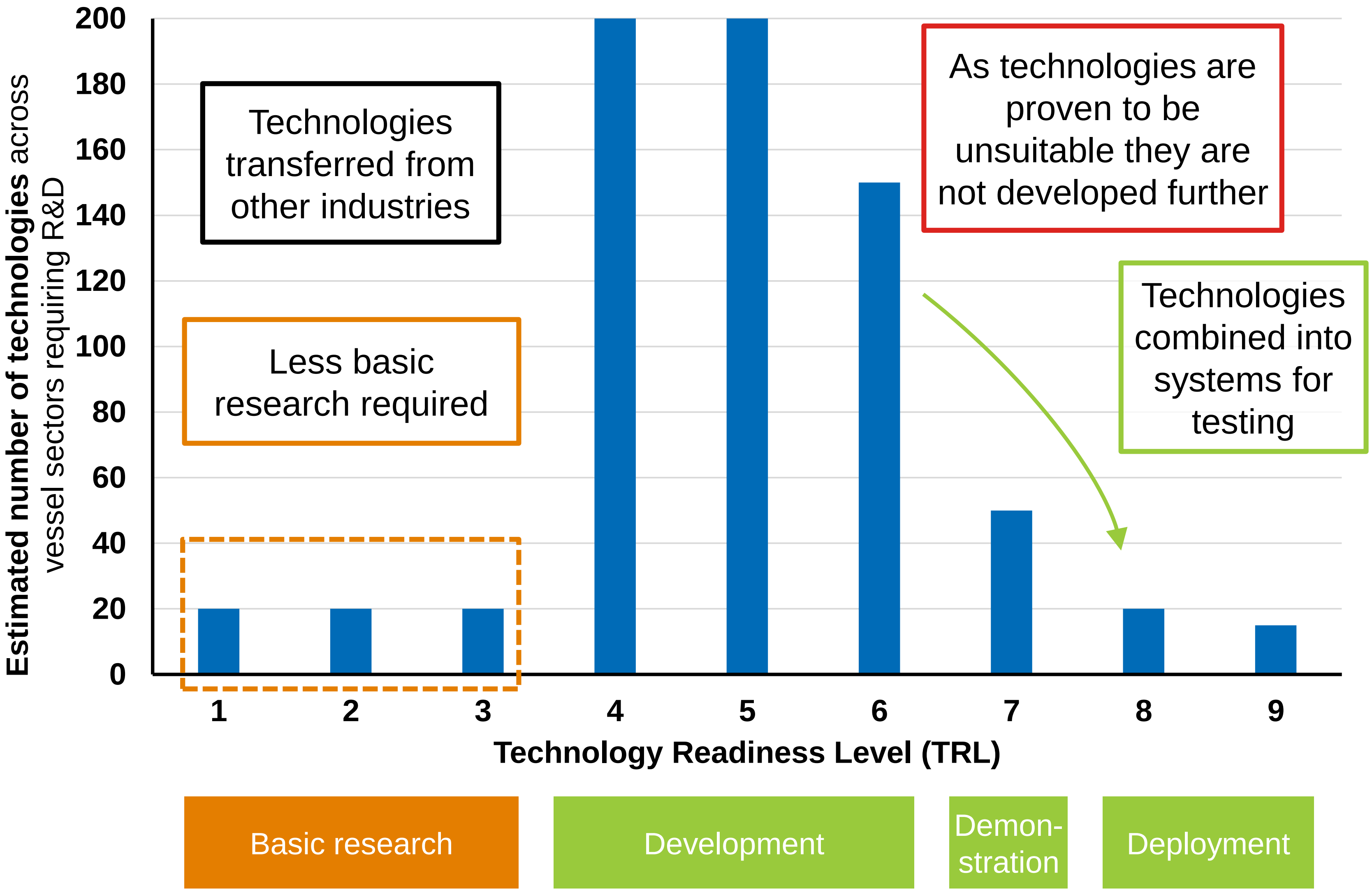
Technology Readiness Levels (TRL) show the steps required from research through to on vessel deployment

TRL	Explanation
1	**Basic principles** of scientific research observed and reported
2	**Invention and research** of practical applications
3	**Proof of concept** with analytical and experimental studies to validate the critical principles of individual elements of the technology
4	Development and validation of component in a **laboratory**
5	**Pilot scale** testing of component in a simulated environment to demonstrate specific aspects of the design
6	**Prototype system** built and tested in a **simulated environment**
7	**Prototype system** built and validated in a **marine operational environment**
8	**Active commissioning** where the actual system is proven to work in its final form under expected marine operating conditions
9	**Operational application** of system on a commercial vessel



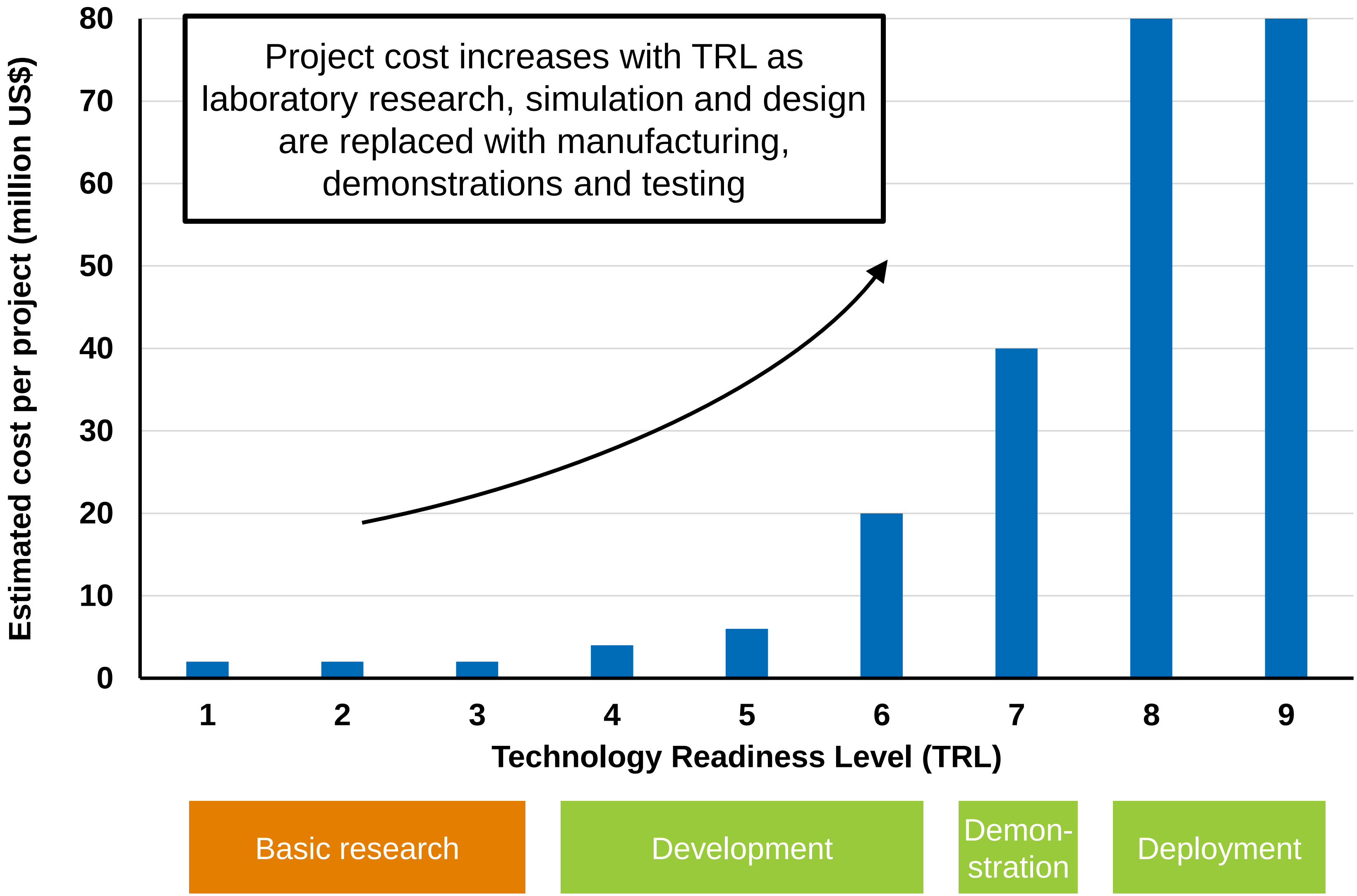
Source: Based on US DoD TRL

At least 200 projects are required for widespread deployment of zero carbon vessels, reducing to 15 to 20 commercial sea trials



Source: Ricardo indicative analysis

Total vessel R&D investment required is estimated to be US$10bn – collaboration will likely be essential to successfully decarbonise



Source: Ricardo indicative analysis

Advantage: zero emission use; fewer moving parts
Gap: significant R&D to scale and ensure robustness for transoceanic

- Renewable electricity = zero carbon
- **A pure battery electric** transoceanic ship would require a battery of ~15 GWh (~tens of kt; ~100x largest battery array)
- **Smaller battery hybrid** vessels offer more commercially viability
  - Internal combustion engine hybrids with zero carbon fuels have potential benefits for entering and leaving ports
  - Fuel cell systems require a battery hybrid system to allow load variation

  ➔ Hybrid zero carbon vessels may still require a relatively large battery array
- Technology transfer from automotive and power industries
- R&D challenges
  - **Electrical system scale**
  - **Robustness** in a harsh environment

Current battery TRL	4 / 5 / 6

Examples of R&D projects

Maintenance of battery systems		$
Vessel system	Energy Storage	Design and development of equipment for safe removal of battery modules at sea, including an on-ship battery systems workshop
Vessel sector	All	
TRL development	4 ➔ 7	

Battery array design and analysis		$$$$
Vessel system	Energy Storage	Design and analysis of a transoceanic battery array for a hybrid power system in a specific vessel class Considering thermal management and design for maintenance
Vessel sector	Array specific to each class	
TRL development	5 ➔ 6	

* Base on an Ultra Large Container Vessel

Hydrogen

Advantages: compatibility, simpler production
Gap: challenges with on-board storage systems and safety

- "Green hydrogen" = zero carbon
- **Compatible power systems**
  - Internal combustion engines (SI & DF)
  - Fuel cells (PEMFC & SOFC)
- **R&D challenges**
  - **Safety** – demonstration projects will be required to demonstrate the risk of explosivity is mitigated
  - **Storage systems** – density and energy requirements to maintain -253°C
  - **Robustness** of fuel cells in a harsh environment and **scaling** of fuel cells
- Limited commercial deployment in other industries

Current hydrogen TRL	3 / 4 / 5

Examples of R&D projects

Safe engine room concept with hydrogen		H_2 $
Vessel system	Engine room	SOLAS: Development of proven guidelines to ensure safe ventilation of hydrogen from engine rooms on transoceanic shipping
Vessel sector	All	
TRL development	5 ➔ 7	

50 MW hydrogen fuel cell system, testing, validation and development		H_2 $$$$
Vessel system	Power system	50 MW fuel cell system manufactured and then tested on-shore over a range of different operating and ambient conditions
Vessel sector	All	
TRL development	5 ➔ 6	

Definitions: Internal Combustion Engine: SI = Spark Ignited, DF = Dual Fuel; Fuel Cell: PEMFC = Proton-Exchange Membrane Fuel Cell, SOFC = Solid Oxide Fuel Cell

Ammonia

Advantage: higher energy density than hydrogen
Gap: R&D needed to address toxicity and fuel cell development

- 'Green ammonia' = zero carbon
- **Storage** as liquid at 10 bar or -33 °C
  - Handling experience from the chemical industry
- **Compatible power systems**
  - Internal combustion engines (SI & DF)
    - Development required and a supporting fuel
  - Fuel cells (SOFC)
- **R&D challenges**
  - **Safety** – ammonia toxicity, so vigorous R&D will be required to ensure that ammonia is not released to atmosphere under any circumstance
  - **Robustness** of fuel cells in a harsh environment and **scaling** of fuel cells

Current ammonia TRL	2 / 3 / 4 / 5

Examples of R&D projects

Ammonia cold start emissions strategy		NH_3 $
Vessel system	Power system	Development of a strategy and technology system to prevent release of ammonia into the atmosphere before the aftertreatment is effective
Vessel sector	All	
TRL development	4 ➔ 5	

Waste heat recovery demonstration in vessel with ammonia fuel cell		NH_3 $$$$
Vessel system	Power system	On vessel demonstration system for use under commercial shipping activities
Vessel sector	All	
TRL development	7 ➔ 8	

A multi disciplinary technology approach to R&D is needed promptly across the shipping industry for effective decarbonisation by 2050

For new energy carriers new on vessel technology will be required, with likely different solutions for each sector, vessel types and routes

- Fuel storage
- On vessel fuel transportation
- Propulsion
- Auxiliary power
- Waste heat recovery
- Refrigeration
- Emissions control
- Engine room safety
- Wider vessel safety
- Vessel configuration and cargo
- Voyage adjustments & re-optimisations
- Logistics adjustments & re-optimisation
- and many more

+ Vessel efficiency will need to increase to reduce freight / tonne energy demands

- Hull drag reduction
- Assistance technology
- Propeller efficiency
- Superstructure drag
- and many more

+ Fuel R&D

+ Shoreside infrastructure

Circa US$10 billion are required for on vessel and power system R&D

R&D driven decisions on fuels need to happen promptly for a zero carbon fleet by 2050